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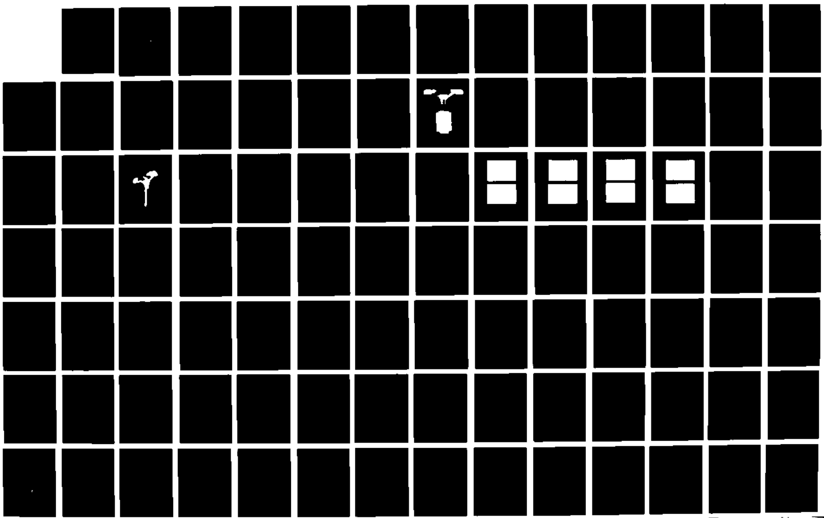

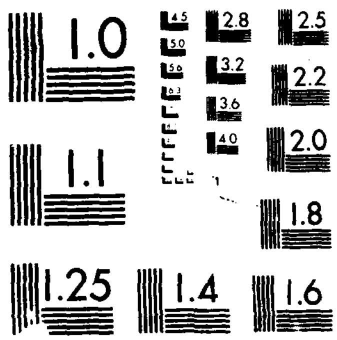
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AFGL-TR-88-0329

AD-A207 669

A PROGRAM TO IMPROVE PERFORMANCE OF AFGL AUTOMATED PRESENT WEATHER OBSERVING SENSORS

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1 August 1988

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2 APRIL 1985 - 31 MAY 1988

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AIR FORCE GEOPHYSICS LABORATORY
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"This technical report has been reviewed and is approved for publication"

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Under a prior Air Force (AFGL) program two prototype Automated Present Weather Sensors were developed. The present program supported hardware and software upgrades to those sensors which were intended to achieve two objectives. The first and primary objective was to improve the performance capability of the sensors to meet the performance specifications of the NWS-ASOS and FAA-AWOS automated present weather observing systems. The second objective was to provide additional sensor capabilities beyond those required for ASOS/AWOS systems, which improvements would be of value in Air Force applications of present weather sensors. Tests made on the sensors after the upgrades were performed, demonstrated their capability to now meet three of the four basic requirements for ASOS/AWOS present weather sensors, namely: (1) precipitation detection, (2) false alarm rate, and (3) precipitation identification. Their ability to meet the fourth requirement; i.e., rainrate accuracy, could not be verified for lack of adequate reference standards. Some

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19. ABSTRACT (continued)

additional capabilities were added to the sensors, but several highly desirable capabilities were not achieved; these were: (1) the identification of hail and ice pellets, (2) the identification of mixed precipitation, (3) the measurement of densities of various snow particle types, and (4) the ability to distinguish between fog or smoke/dust as an obstruction to vision. Late in the program, a backscatter receiver channel was added to one of the sensors. Preliminary indications are that the measurement of backscatter radiations from precipitation particles, along with the standard forward scatter measurements, can provide the necessary information to attain those goals which were not achieved during the program.

Cont of Block 18:

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1.0 INTRODUCTION

1.1 Background

Under a prior contract with HSS Inc, the Air Force supported a program for the development of an Automated Present Weather Sensor based on an invention by two of the authors. Two sensors were developed under that program. The first of these was termed a Laboratory Model Sensor (as opposed to an operational model) because it did not have an on-board microprocessor; rather it used a remotely located personal computer to perform the data collections, data analysis, real-time reporting functions and storage of data.

Based on the knowledge gained with the Laboratory Model Sensor a second, Field Model Sensor, was developed. The Field Model Present Weather Sensor had an on-board microprocessor which analyzed precipitation and obstruction to vision data. At the end of each sampling time period, a report was sent to a user terminal. the sensor then dumped the analyzed data and began the collection and analysis process all over again.

Both the Laboratory Model sensor and the Field Model sensor were tested extensively at the Air Force Geophysics Laboratory (Weather Test Facility) at Otis ANGB, MA. The results of those tests were presented in a final report under the Air Force Contract (Reference 1). That report delineated the capabilities of the HSS Inc Automated Present Weather Sensor and established goals and approaches to those goals for improving and expanding the capabilities of this type of Present Weather Sensor.

In a subsequent procurement the Air Force addressed the goals of improved and expanded capabilities for the two present weather sensors. This report describes that program and its results.

1.2 Present Weather Definition

The term "Present Weather" as employed in the Federal Meteorological Handbook (Reference 2) includes a large class of atmospheric phenomena (e.g., tornadic activity, thunderstorm activity, precipitation, obstructions to vision, and "other" atmospheric phenomena such as aurora). For purposes of this program, the term present weather refers to those atmospheric phenomena which are local to an Automated Present Weather Observing Sensor. These phenomena include: (1) all forms of liquid and frozen precipitation, e.g., rain, drizzle, snow, snow pellets, snow grains, ice pellets (formerly sleet) and hail, and (2) those suspended particles which are classed as obstructions to vision; namely, mist, fog, haze, dust and smoke.

1.3 HSS Inc Present Weather Measurement Technique

The unique capabilities of the HSS Inc present weather observing sensors derives from their ability to measure the size and velocity of each precipitation particle that passes through the sample volume of the sensor head. After the passage of a precipitation particle through the sample volume the size and velocity information is stored in a data matrix by a data processing system. Particle size/velocity data is collected and stored for a time interval (the sample time period) adequate to provide a statistically significant and representative sample of particle sizes and velocities. At the end of the sample time period, the size/velocity matrix is analyzed utilizing software algorithms which identify the type of precipitation and measure its rate of fall.

An adjunct capability of the HSS Inc present weather sensors is the measurement of the atmospheric extinction coefficient, hence visual range. As a result, the instrument has three basic capabilities: (1) the detection, identification, and quantification of the various forms of precipitation: (2) the ability to discern whether an obstruction to vision is caused by precipitating particles or by suspended particles (i.e., haze, fog, smoke or dust); and (3) the ability to separate the fraction of the total atmospheric coefficient due to suspended particles from the portion due to precipitating particles.

An abbreviated description of the present weather measurement technique may be found in Appendix A. A more complete description may be found in Reference 1. The HSS Inc present weather measurement technique has been granted U.S. patent No. 4,613,938 and Canadian Patent No. 1,229,240. Patents are also pending in several other countries.

Throughout this report the abbreviated term <u>EXCO</u> is substituted for the more complete term Atmospheric Extinction Coefficient, and the abbreviated term <u>EXCO MINUS EVENTS</u> is substituted for the more complete phrase Atmospheric Extinction Coefficient with the effects of Precipitation Removed.

2.0 PROGRAM TO UPGRADE SENSOR PERFORMANCE

2.1 Program Objectives

The Air Force has not, as yet, established a set of performance requirements for present weather sensors. Both the Federal Aviation Authority (FAA) and the National Weather Service (NWS) have, however, established performance requirements for present weather sensors. In the absence of specific Air Force requirements, the FAA and NWS performance requirements were utilized as objectives for the present program.

The FAA performance requirements for present weather sensors which were established by the FAA for their Automated Weather Observing Systems (AWOS) are described in Reference 3. The FAA performance requirements which were similarly established by the NWS for their Automated Surface Observing System (ASOS) may be found on Reference 4.

The NWS-ASOS performance requirements for present weather sensors are provided in Table 2.1. Those for the FAA-AWOS sensors do not differ significantly, thus will not be repeated here other than to call attention to three instances in which their reporting procedures differ. In the first instance, the FAA does not require an intensity assignment (e.g., R-, R, R+) to the type of precipitation. In the second instance, the FAA does require an accelerated notification of the onset of precipitation (e.g., for precipitation rates of 0.11 inches per hour or more the sensor shall detect the onset of precipitation within one minute). Finally, the FAA performance requirements for identification of precipitation type varies with ambient temperature ranges.

A thoughtful study of both the NWS-ASOS and FAA-AWOS performance requirements for present weather sensors will conclude, we believe, that the AWOS requirements are in the main contained within the ASOS requirements and thus, we need only address the ASOS requirements. We point out, however, that neither set of performance requirements explicitly specifies some essential testing parameters (e.g.,): (1) the number of operating hours that a sensor must be subjected to the various forms of precipitation when evaluating identification performance, (2) the period of the time over which the false alarm rate is to be evaluated, and (3) a precipitation rate threshold level for evaluating the false alarm rate.

At the outset of this program a plan was established that had as its objectives: (1) meeting the AWOS/ASOS performance requirements, and (2) extending the sensor capabilities beyond those needed to meet the AWOS/ASOS requirements and into other

Table 2.1. National Weather Service Performance Requirements for the ASOS Present Weather Sensor.

The Present Weather Sensor shall meet the following functional and engineering requirements:

- The rainfall and wet snowfall detection threshold shall be a rate of 0.01 inch per hour, as measured using a standard NWS Tipping Bucket.
- The precipitation rate accuracy shall be the larger of 10% or 0.01 inches/hr.
- The solid precipitation shall be correctly detected at least 99% of the time (reported as either "S" or "P") and shall be correctly identified at least 97% of the time.
- The liquid precipitation shall be correctly detected at least 99% of the time (reported as either "R", "L" or "P") and shall be correctly identified at least 90% of the time.
- The false alarm rate shall be less than or equal to 0.2%.
- The sensor shall provide sufficient data to the Present Weather Algorithm Appendix A so that the following weather situations can be identified:

Light Drizzle	(L-)
Moderate Drizzle	(L)
Light Rain	(R-)
Moderate Rain	(R)
Heavy Rain	(R+)
Light Snow	(S-)
Moderate Snow	(S)
Heavy Snow	(S+)
Mixed or other Precipitation	(P)

- The sensor shall report the start or end of a present weather event within five minutes of the time that a certified observer would so report.
- The sensor shall be interrogated once per minute.

Source of Requirements: See Reference 4

areas of concern and interest to the Air Force. These two broad objectives were addressed by outlining specific objectives and separating them into two categories:

PRIORITY UPGRADE GOALS

- Detect and Identify Drizzle
- Improve Rain Identifications
- Improve Snow Identifications
- Improve False Alarm Discrimination
- Identify Hail and Ice Pellets
- Provide Transmissometer Equivalent EXCO's
- Assess Rainrate Algorithm Accuracy
- Increase Ambient Temperature Operating Range
- Evaluate VR-301A Visibility Sensor as a Possible Present Weather Sensor

DESIRABLE UPGRADE GOALS

- Identify Mixed Precipitation
- Distinguish Between Fog and Smoke/Dust as an Obstruction to Vision
- Resolve Differences in the Density of Snow Particle Types
- Provide Graphic Video Display of Rainrate and Visual Range at Control Computer
- Provide Semi-Automatic Calibration Checks
- Transmit Precipitation Identification Matrices from Sensor to Control Computer
- Improve Algorithm to Distinguish Fog in the Presence of Precipitation

2.2 Hardware Upgrades

The upgrade program for the two Air Force present weather sensors began in the summer of 1986. The program was intended as a mixture of software improvements and minor hardware upgrades. Fortuitously, HSS Inc received an SBIR contract award from the Army that same summer for the development of a compact, portable, lightweight, battery-powered present weather sensor (eventually called the Model PW-403 Present Weather Sensor). Under the Army contract, improved circuit boards with an extended operating temperature range (-40°C to +85°C) were developed. Since the Air Force sensors were experimental in nature with handwired circuit boards, a low-cost upgrade to printed circuit boards was readily available once the PC boards for the Army sensors were developed.

2.2.1 Field Model Sensor

Because the field model sensor has an on-board microprocessor and, therefore, is the prototype for all future present weather sensors of the HSS Inc type, it was the obvious choice with which to begin the hardware phase of the upgrade program. One important objective of the hardware upgrades was to enable the field model sensor to detect drizzle and measure its intensity. Drizzle is composed of fine water drops having a diameter less than 0.5 millimeter (radius of 250 microns). In order to accomplish that task it was necessary to increase the signal-to-noise (S/N) characteristics of the instrument, since any attempt to lower the particle detection threshold level would increase false alarms generated by noise spikes.

An increase in S/N ratio was brought about by changes to the optical transmitter. A new transmitter design incorporated a higher power IRED source to improve the sensitivity of the instrument thus allowing it to detect particles of smaller size. The higher power IRED, in turn, required an upgrade of the transmitter circuit board to provide increased power to the IRED.

Another new feature was added to the transmitter at the same time; namely, a photodiode monitor of the IRED light output, with an accompanying feedback circuit to stabilize the light output of the IRED at a constant value. Light output from an IRED degrades by 20 percent over its ten year expected lifetime. The output is also temperature dependent. In the past, HSS Inc had stabilized the IRED against temperature variations by housing it in a small crystal oven. Source fatigue was previously compensated for by requiring a yearly calibration check of the instrument.

The field model sensor was operated for a period of time at HSS Inc after the hardware modifications and then returned to the AFGL Weather Test Facility (WTF) at Otis ANGB. During the following several weeks, experiments were conducted to empirically find the optimum particle detection threshold for rejection of random electronic noise spikes. If the threshold is set too high, instrument sensitivity to drizzle and light rain is reduced. If the threshold is set too low, noise spikes caused by glints from sunlit objects in the background scene viewed by the detector can cause false alarms which, in turn, brings the false alarm discrimination algorithms into excessive use.

Prior to the transmitter modification, the threshold was set at a particle radius of 265 microns (.265 millimeters). After the modification, it was found that the instrument could be operated at a particle threshold setting of 212 microns. This result is equivalent to a 50 percent improvement in the sensitivity of the instrument. At a later date, an adaptive threshold technique was invented for the receiver that enabled the sensor to

detect particles with radii as small as 160 microns. This change represented an overall 270 percent increase in sensitivity of the sensor.

HSS Inc had proposed eight specific hardware upgrades to the Air Force. Six of these fell into the Priority Goals Category, the remaining two into the category of Desirable Goals. The six hardware upgrades, which were incorporated into the field model sensor and all subsequent present weather sensors manufactured by HSS Inc are listed below. In many cases, the hardware upgrades were accompanied by associated software upgrades.

1. A higher power IRED source was incorporated into the transmitter.

2. The light output of the IRED was stabilized against temperature variations using a photodiode and feedback circuit, which also stabilized against source fatigue.

3. The sensor EXCO calibration check was made semi-automatic. Any readjustment can now be performed at the control computer terminal, or locally at the sensor using a portable hand-held computer such as the Radio Shack Model 100. It is first necessary to manually install the calibration reference standard. The equivalent EXCO value of the reference standard is then sent by the operator via either terminal to the on-board microprocessor along with a command to check the instrument EXCO calibration. The sensor first self-checks its zero reading then its reading on the reference standard. If any changes are required, they are automatically made in software parameters rather than laboriously removing covers from the sensor head and adjusting potentiometers.

4. In a manner similar to the self-check of the atmospheric extinction coefficient calibration, a self-check of the on-board temperature sensor can be made from the desktop computer terminal or from a portable hand-held computer. It is only necessary to type in the temperature check command and the correct ambient temperature. If the on-board temperature sensor is providing a reading different from the correct ambient temperature reading then the on-board temperature sensor calibration will be automatically changed to provide the correct reading.

5. The precipitation size/velocity matrix can now be sent from the sensor to the user terminal for permanent storage.

6. A new on-board microprocessor employs CMOS solid state electronics. This upgrade coupled with the use of industrial grade electronics throughout allows the field model sensor and all newer present weather sensors to meet an operating ambient temperature range requirement of -40°C to 85°C.

The remaining two hardware upgrades suggested by HSS Inc were: (1) the incorporation of an on-board relative humidity sensor and (2) acceptance of wind speed and direction input signals from the MAWS system. The on-board relative humidity sensor was intended to provide the necessary input to the present weather sensor to distinguish

fog from smoke or dust. The acceptance of wind speed/direction from the AFGL Weather Test Facility MAWS system was intended as a diagnostic tool for assessing the accuracy of the precipitation and accumulation algorithms under varying wind conditions. Neither of these hardware upgrades were implemented due to the need to concentrate on achieving the priority goals.

2.2.2 Laboratory Model Sensor

The Laboratory Model Present Weather Sensor is an anachronism in that no operational sensors will utilize the same remote microcomputer approach. Another anachronism is that the software for the laboratory model sensor is peculiar to that sensor and unlike the software of the field model sensor subsequent operational sensors.

A thorough review of the extensive changes required to upgrade the laboratory model sensor was conducted with the AFGL contract technical monitor. The result was a decision not to make any extensive upgrades to the laboratory model sensor. Rather, it was decided to retain the Laboratory Model sensor essentially as it was and use it as a reference instrument to gauge how well the upgrades incorporated in the Field Model sensor and other newer, operational model instruments have improved the performance of the HSS Inc type of present weather sensors.

2.2.3 Operational Model Sensors

The laboratory and field model sensors evolved from the independently developed HSS Inc Model VR-301 Visibility Sensors by adding a microprocessor to determine the size and velocity of precipitation particles passing through its sample volume and by applying algorithms to identify the form of the precipitation, and measure its rate of fall.

By 1985 a long testing experience with the VR-301 had demonstrated that the optical transmitter and receiver should be separated by a greater distance to prevent rain splatter off their hoods from appearing in the sample volume along with the falling rain. It was further established that the sample volume should be elevated above the back mount which supports the transmitter and receiver arms, again to prevent rain splatter from getting into the sample volume, but also to prevent any impediment to the free flow of fog into the sample volume.

The design changes required to eliminate the problems of the VR-301 resulted in the Model VR-301A Visibility Sensor. A prototype VR-301A was fabricated in 1985

under an internal HSS Inc R&D program. The Model VR-301A sensor head configuration was then used for all operational type present weather sensors. The latter was given a Model PW-402A designation.

In August 1986, the Department of Transportation (DOT) announced a seven month test program for present weather sensors to be conducted at the AFGL Weather Test Facility during the winter of 1986/1987. The DOT recommended that two sensors be provided so that testing could be continued uninterrupted in the case of a malfunction of one of the sensors. HSS Inc elected to fabricate sensors of the new Model PW-402A configuration (see Figure 2.1) for the DOT/FAA Test Program.

In September 1986, the NWS requested the lease of an instrument similar to those being fabricated for the DOT/FAA for testing at the NWS Sterling, VA test site during the winter of 1986/1987. HSS Inc then commenced fabrication of a third sensor with the new PW-402A configuration.

The increased separation of the optical transmitter and receiver of the Model PW-402A enlarged the sample volume of the sensor from 400 cm^3 to 800 cm^3. It had earlier been established that the 400 cm^3 was roughly optimum for an HSS Inc type of present weather sensor since it provided a low probability of two precipitation particles being present in the sample volume of any instant of time, thus permitting an unambiguous determination of particle size and velocity even in the heaviest of rainfalls.

After some preliminary experience with the Model PW-402A in rain episodes, it was concluded that indeed the sample volume was too large and should be reduced to near the optimum size of 400 cm^3.

A reduction in size of the PW-402A sample volume from 800 cm^3 back to approximately 400 cm^3 was accomplished by increasing the focal length of the projection lens in the transmitter. The increase in focal length had the net effect of reducing the diameter of the projected bundle of light at the sample volume.

By the end of 1986 HSS Inc had completed the fabrication of three Model PW-402A operational type present weather sensors. These sensors are identified by their reporting ID Numbers as PW-03, PW-04, and PW-05 as indicated in Table 2.2. It was necessary to assign ID No.'s to each of the instruments so that the many sensors under test by the DOT, NWS and Air Force could be correctly identified by their data logging equipment. The Laboratory Model Sensor and Field Model Sensor were designated ID Numbers PW-01 and PW-02 respectively.

The WSMR present weather sensors listed in the table were not part of any formal testing program, but had to be identified so that their measurement data would not be confused with that of any other sensor.

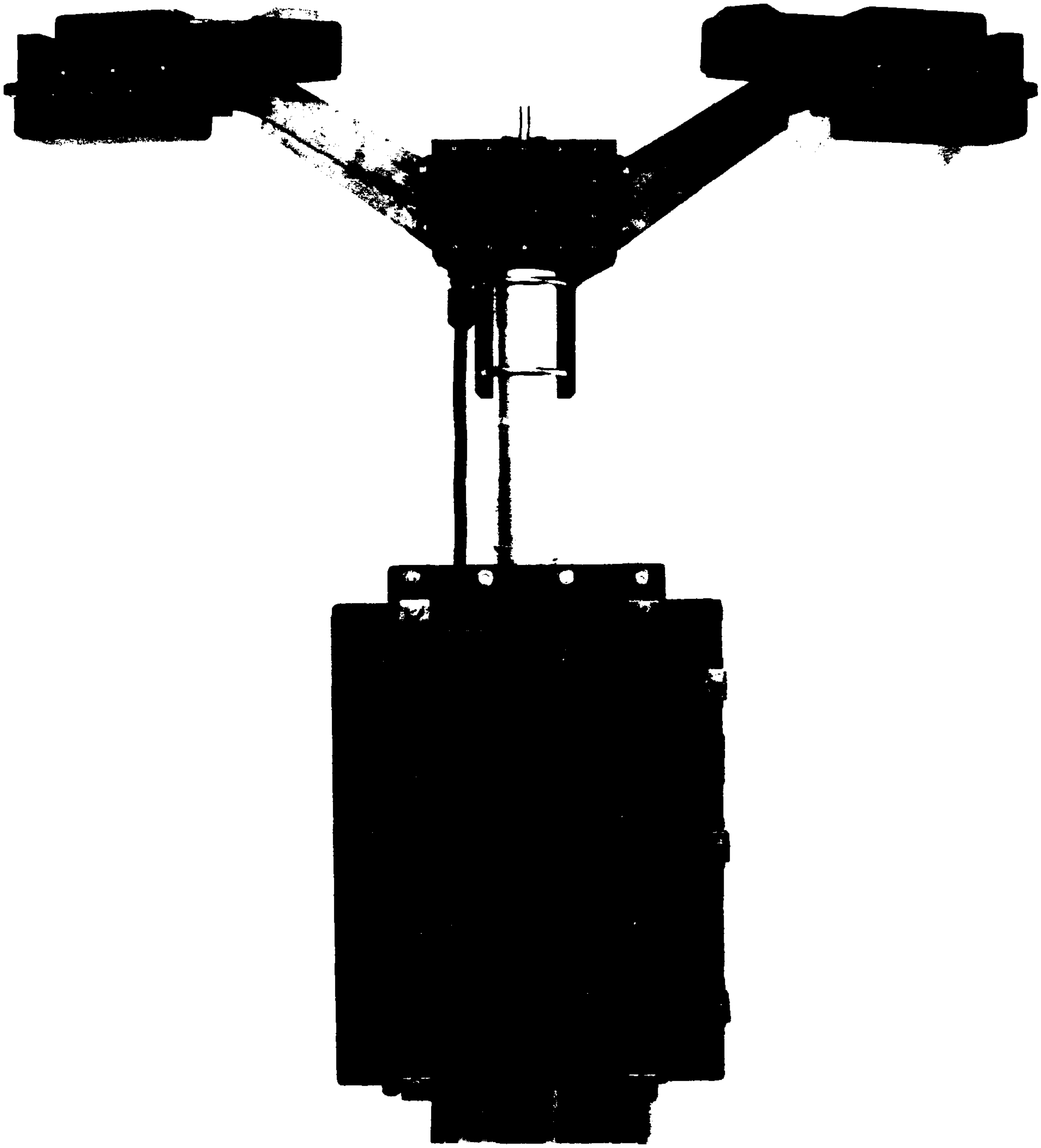


FIGURE : 2.1. The Model PW-402A Present Weather Sensor.

Table 2.2. Information Pertinent to HSS Inc Type Present Weather Sensors Used in Various Test Programs.

REPORTING ID NO.	IDENTIFYING NOMENCLATURE			TEST LOCATION	
	PROPERTY OF	MODEL	S/N	Winter 1986/1987	Winter 1987/1988
PW-01	AFGL(Lab Model)	PW-401	013	Otis ANGB	Otis ANGB
PW-02	AFGL (Field Model)	PW-402	012	Otis ANGB	Otis ANGB
PW-03	HSS Inc	PW-402A	055	Otis ANGB	Worcester, MA
PW-04	HSS Inc	PW-402A	095	Otis ANGB	Otis ANGB
PW-05	HSS Inc	PW-402A	100	Sterling, VA	Fairbanks, AK
PW-06	WSMR	PW-402	001	- -	- -
PW-07	WSMR (Prototype)	PW-403	001	- -	Otis ANGB
PW-08	Not Assigned	- -	- -	- -	- -
PW-09	NWS	PW-402A	109	N.A.	Otis ANGB
PW-10	NWS	PW-402A	110	N.A.	HSS Inc
PW-11	NWS	PW-402A	111	N.A.	Otis ANGB

For completeness of the sensor identification table three other Model PW-402A sensors are listed. These sensors were not used in the winter of 1986/1987 test program since they were not fabricated until late 1987. They were included in the winter 1987/1988 test program.

2.3 Software Upgrades

In addition to the software modifications associated with the hardware improvements, a number of strictly software upgrades were incorporated in the proposed program. Again, these upgrades fell into two categories, priority upgrades and desirable upgrades. The software improvements are described in the following sections.

2.3.1 Priority Upgrades

2.3.1.1 Change of Reporting Codes

Prior to the winter of 1986/1987, the HSS Inc Present Weather Sensors reported obstruction to vision using the International Visibility code. That code has ten visibility classifications ranging from Exceptionally Clear to Dense fog. Precipitation type and intensity were reported in words: (e.g., light rain, heavy snow, etc.). Drizzle was reported as rain, if it was detected at all.

To bring all automated present weather sensors into a common 1987/1988 reporting scheme for the winter tests, the DOT, Air Force and NWS agreed upon the use of the NWS weather observation code as practiced by human observers. In that reporting code, symbols are used to characterize the type and intensity of precipitation, as shown in Table 2.3. Obstructions to vision are reported as either haze (H) or fog (F). An additional symbol (P) is included for automated sensors to report unidentified precipitation. (NP) is added to definitize the fact that no precipitation was detected.

The revised HSS Inc reporting code took two minor exceptions to the NWS reporting code: (1) heavy drizzle is reported as L+, whereas there is no heavy drizzle category in the NWS reporting code, and (2) very light unidentified precipitation is reported as (P-) instead of P. The fact that the HSS Inc sensors can distinguish heavy drizzle from drizzle or light rain led HSS Inc to include (L+) in its reporting code.

During the winter of 1986/1987, HSS Inc employed several additional symbols in its reporting code in an attempt to identify mixed precipitation. By late 1987, however, all sensors but the Laboratory Model sensor used the NWS reporting code shown in Table 2.3. The Laboratory Model sensor continues to report in the pre-1986 manner.

Table 2.3 Reporting Codes Employed in the HSS Inc Automated Present Weather Sensors: 1986-1988.

(A) INTENSITY OF DRIZZLE (RATE OF FALL BASIS)

Classification	Rate of Fall (in/min)	Reporting Symbol
Trace	Less than 0.000083	L-
Light	Trace to 0.00017	L-
Moderate	0.00017 tc 0.00033	L
Heavy	More than 0.00033	L+

(B) INTENSITY OF RAINFALL

Classification	Rate of Fall (in/min)	Reporting Symbol
Trace	Less than 0.000083	R-
Light	Trace to 0.0017	R-
Moderate	.0017 to 0.005	R
Heavy	More than 0.005	R+

(C) INTENSITY OF SNOWFALL (VISIBILITY BASIS)

Classification	Visual Range (miles)	Reporting Symbol
Light	More than 5/8	S-
Moderate	5/16 to 5/8	S
Heavy	Less than 5/16	S+

(D) OBSTRUCTIONS TO VISION

Classification	Visual Range (miles)	Reporting Symbol
Haze	7.0 to 3.0	H
Fog	Less than 3.0	F

(E) UNIDENTIFIED PRECIPITATION

Classification	Rate of Fall (particles/min)	Reporting Symbol
Very Light	Less than 30	P-
Light to Heavy	30 or More	P

2.3.1.2 Transmitter Equivalent EXCO

The HSS Inc Present Weather sensors also function as forward scatter visibility sensors. Forward scatter visibility sensors are known to report larger values of extinction coefficient in rain than do transmissometers. The reason for this disparity is a phenomenon peculiar to the transmissometers.

During rain the light projected by the transmitter of a transmissometer can reach the receiver by two paths: first, it can follow a direct path whereby it does not suffer a scattering collision with a raindrop; secondly, if some of the projected light does scatter from raindrops, an amount equal to one-half of the scattered light is diffracted in a highly forward direction and thus can enter the receiver. The diffracted component of light adds to the unattenuated light thereby reducing the measured attenuation coefficient.

A forward scatter visibility sensor operating at the central scattering angle of 35 degrees does not "see" the diffracted component of light, which is included in an angle less than one degree. Hence, the sensor measures the true attenuation coefficient.

Although the transmissometer measures a lower EXCO value than the true value in rain, there is a school of opinion that believes that the transmissometer EXCO value provides visual ranges more in agreement with human observers than do EXCO values measured by forward scatter meters. The argument for their case is that that there is a similarity between a transmissometer and the eye/target relationship of the human observer.

Another school of opinion has it that indeed there is a similarity between a transmissometer and the human observer when the target is a point source of light, but not for the case where the target is a non-self lumininous object. In this latter situation, the airlight (i.e., light scattered by raindrops and aerosols) reduces the target/background contrast in accordance with the law of contrast reduction. The law of contrast reduction determines visibility on the basis of the of the total extinction coefficient. Thus, in the case of non-luminous objects forward scatter meters may well provide visibility values in rain that are more in accord with human observers than are those of transmissometers.

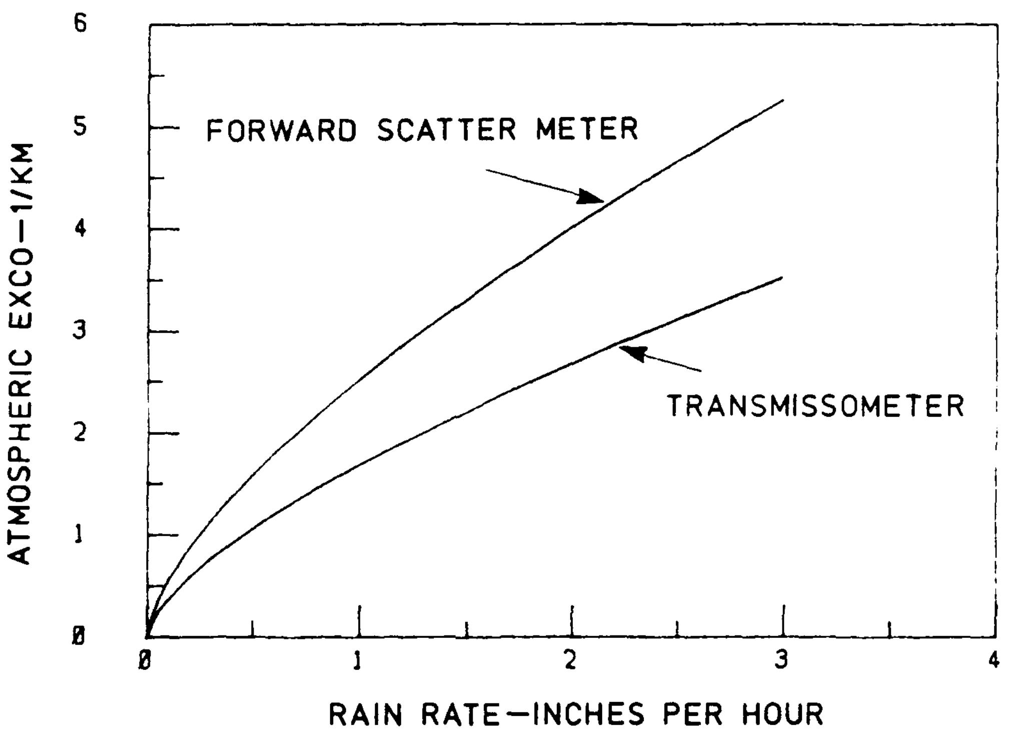
Transmissometers remain the primary reference standard against which all visibility sensors are calibrated and judged. This is because they provide absolute values of the atmospheric extinction coefficient rather than relative values. Scatter meters measure relative values of the atmospheric extinction coefficient which are converted to absolute values by means of calibration constants obtained by comparison of readings from prototype sensor with those of a transmissometer. Because the

transmissometer retains this honored position, it is widely accepted that measurements by all other types of visibility sensors must agree (within acceptable limits) with those of transmissometers in all forms of weather (haze, fog, rain, snow, etc.).

The HSS Inc forward scatter meter readings agree well with transmissometer readings in haze, fog and snow. In rain it records higher EXCO values than a transmissometer, but within acceptable limits. One goal of the program was to develop the software to bring the visibility measurements during rain to accord with those of a transmissometer. To make the measurements agree in rain required a knowledge of the response of each type of instrument to various intensities of rain. A brief empirical study was conducted using two HSS Inc forward scatter meter response located near a 500 foot baseline transmissometer at the AFGL Weather Test Facility at Otis ANGB. It was found that the forward scatter meters and the transmissometer response followed a power law behavior, but with different exponents as shown in Figure 2.2. The power law results obtained for the 500 foot transmissometer agree well with those given in References 5 and 6.

The results of this investigation have been incorporated into the on-board micro-processor calculations of the present weather sensors. Values of the TRANSMISSOMETER EQUIVALENT EXCO are included in the message sent to the control computer along with the total EXCO and EXCO MINUS EVENTS. At present, visual ranges provided by the present weather sensors are determined from the total EXCO. The TRANSMISSOMETER EQUIVALENT EXCO could be used for that purpose should the operator choose to do so.

It should be noted, the HSS Inc Present Weather Sensors can provide the TRANSMISSOMETER EQUIVALENT EXCO without reference to any other sensors because the Present Weather Sensors measure both the total EXCO and RAINRATE as required by the equation for σ (adjusted) in Figure 2.2.



POWER—LAW ATTENUATION COEFFICIENT β IN RAIN

TRANSMISSOMETER : $\beta = 1.69R^{2/3}$

FORWARD SCATTER METER : $\beta = 2.53R^{2/3}$

WHERE : β = ATMOSPHERIC ATT'N.COEFF.,1/KM

R = RAIN RATE,INCHES PER HOUR

$$\beta_{ADJ} = \beta_{MEAS} - \left\{ 2.53R^{2/3} - 1.69R^{2/3} \right\}$$

$$\beta_{ADJ} = \beta_{MEAS} - 0.84R^{2/3}$$

FIGURE : 2.2. Rainrate Adjustment to convert Forward Scatter Meter EXCO Measurements to Transmissometer EXCO Measurements.

2.3.1.3 Improve Precipitation Identification Accuracy

At the outset of the program, the plan to improve the accuracy of precipitation identification was straightforward. Archived data from the previous year, (i.e., precipitation identification matrices) that encompassed a variety of snow and rain episodes, would be used to test upgraded identification algorithms. By the iterative process of modifying and retesting, the algorithms would be improved to the point where they had the desired identification accuracy.

This seemingly straightforward plan did not anticipate the radical changes in the precipitation identification matrices that resulted from the large increase in sensitivity to small particles brought about by the hardware changes. When it was discovered late in 1986, after the hardware changes were complete, that the identification matrices were dramatically changed as a result of the increased sensitivity to small particles, the original upgrade plan had to be abandoned. It then became necessary to collect new matrix data for analysis and subsequent redrafting of the identification algorithms.

Algorithm redrafting began after the hardware upgrades were complete, that is shortly before the winter of 1986/1987 set in. A small amount of rain data was collected before the precipitation episodes changed entirely to snow. The algorithms were hastily revised in time for the mid-January start of the DOT and NWS test programs. After the test programs were concluded, revision of the identification algorithms continued using archived data from snow episodes and from post-winter rain episodes.

The winter of 1986/1987 tests demonstrated several inadequacies in the identification capabilities of the sensors. The inadequate performance was thought to result from the haste in which the identification algorithms were prepared and the small data base from which they were derived.

There was every expectation that the algorithms that were finalized after completion of the 1986/1987 winter tests would demonstrate a considerable improvement in precipitation identification accuracy by the sensors during the following winter (1987/1988). Such was not the case. Algorithms that worked well in instruments located at HSS Inc did not work well at Otis ANGB, where the testing took place. The difference in performance was readily traced to the high wind conditions at the latter site.

Precipitation identification algorithms for HSS Inc present weather sensors normally depend heavily on the use of particle size/velocity distributions. Under strong wind conditions, such as those that prevail during winter and spring storms on Cape Cod, the particle velocity distribution is skewed making it an unreliable discriminator for

use in precipitation identification. Several attempts were made early in the 1987/1988 winter to adapt the algorithms to the skewed velocity distributions, but with limited success.

It was finally concluded that particle velocity must be replaced by another piece of information as an identification discriminator. Several possibilities were considered, the most promising of which was the addition of a second receiver to measure the scattering coefficient at an angle considerably different from that of the primary receiver which is 35 degrees.

Having decided to add a second receiver, the remaining question to resolve was the optimum scattering angle. A review of the angular scattering properties of snow, rain, fog and haze led to the conclusion that the optimum measurement angle for a second receiver was near 100 degrees. Around that angle water droplets, fog particles and haze aerosols have a pronounced scattering minimum. Scattering by snowflakes is more uniform at all angles.

The second receiver is designed to mount on the bracket provided on the junction box which is situated between the transmitter and receiver arms. The bracket is normally used to mount the calibration reference standard only when performing a calibration check. The electronics associated with the second receiver are housed within the junction box. A photograph of the PW-402A with the second receiver installed is shown in Figure 2.3.

A single prototype receiver was fabricated and incorporated into the PW-04 sensor during January 1988. After a brief test period at HSS Inc, the sensor was moved to Otis ANGB where it was installed on 2 February 1988.

During the short test period at HSS Inc one snowstorm occurred, and shortly after the installation at Otis ANGB, a rain episode occurred with a changeover to snow. From the data obtained on those two episodes algorithms were developed to assist in the precipitation identification. The result was a dramatic improvement in the accuracy of the identifications. Those same algorithms were used throughout the rest of the winter without change.

The improvement in precipitation identification accuracy started out as a planned software upgrade. The most innovative solution turned out to be a hardware upgrade. Nevertheless, it is reported here under priority software upgrades since, under the original plan, that was the intent. Needless to say, several hardware upgrades resulted in changes to the software as was previously noted. Similarly, some software upgrades had accompanying hardware changes.

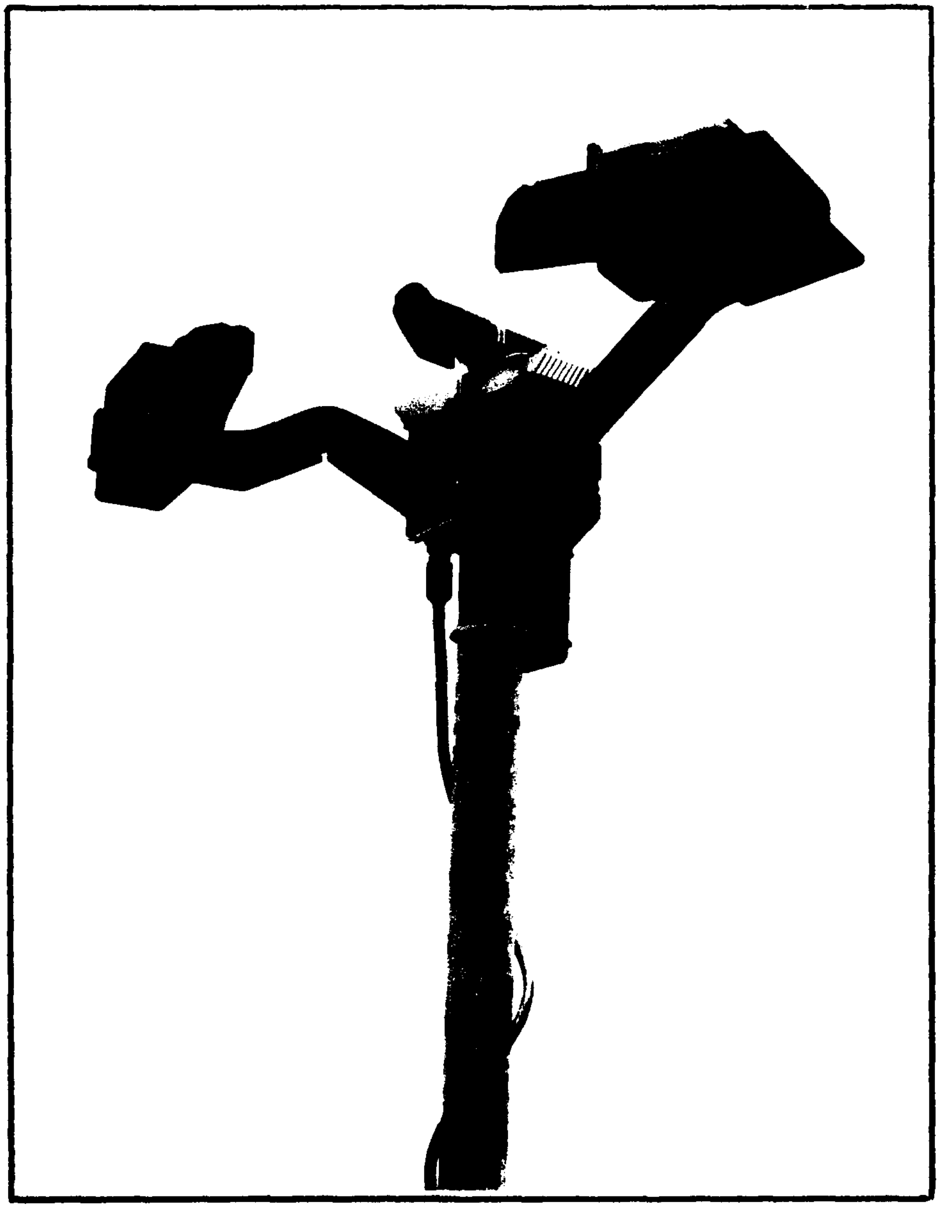


FIGURE 2.3. A Model PW-402A Present Weather Sensor with the Experimental Backscatter Detector Installed, Side View.

2.3.1.4 Improve False Alarm Discrimination Accuracy

The two most probable sources of false alarms in an HSS Inc type of present weather sensor are: (1) noise spikes generated in the primary receiver under high ambient light conditions, and (2) sun glints caused by an image of the sun reflecting off of nearby mirror-like objects in the field-of-view of the primary receiver (e.g., windshields of automobiles). Vibration is not a source of false alarms in an HSS Inc type of present weather sensor. False alarm prevention in the HSS Inc sensors is dealt with in two ways: by rejection in software and by threshold discrimination in hardware.

Most false alarms can be eliminated in software. They invariably appear in the precipitation identification matrix as particles with distinct size/velocity distributions unlike the size/velocity characteristics of any natural precipitation. Algorithms were formulated early in the development of the sensors that reject most false alarms. Plans formulated for the present program called for a continuation of the process of upgrading the algorithms to reject any false alarms which might elude the older algorithms.

False alarms were not considered a serious problem in the HSS Inc sensors since the false alarm rate was already at an acceptable limit. But during the course of the present program the false alarm rate was fortuitously reduced to near insignificance by the same hardware improvements that led to the capability of detecting drizzle size particles. The improvement in S/N ratio brought on by a greater IRED source output and by the adaptive threshold discriminator virtually eliminated detector noise as a source of false alarms. Again, this was a case where a hardware upgrade was substituted for a planned software upgrade.

On one occasion during the winter of 1987/1988, light precipitation (P-) was reported by one sensor near noontime on a cloudless day. The problem was traced to sun glints from windshields of automobiles located in a parking lot less than 100 feet away. A slight turning of the sensor head eliminated the problem. In this instance, the particle size/velocity distribution in the precipitation identification matrices did not differ significantly from those of natural particles.

A software algorithm for rejection of the sun glints based on ambient light level was conceived, but not implemented because the DOT tests were in progress. The sun glint problem is not considered serious because it can only occur when vehicles are parked nearby and are also within the narrow field-of-view of the receiver which is very unlikely in an operational situation. The rejection algorithm can be implemented if it ever becomes necessary to do so.

On some occasions in heavy fog, the sensors report light precipitation when human observers do not. An examination of the precipitation identification matrices

indicates two basically different types of occurrences; one type is classifiable as a false alarm while the other is probably not. In the first type of occurrence the false particles appear in the large/slow bins of the size velocity matrix. These false particles have been identified as being caused by inhomogenieties in wind-blown fog. Algorithms have been developed that reject most, but not all, of these occurrences. Further work is needed in this case.

In the second case, the particles appear as small/slow particles in the size/velocity matrix. In this instance, we believe that the sensors are detecting true particles that are in the mist-size category and the human observers choose not to distinguish them from very large fog particles.

2.3.1.5 Identify Hail and Ice Pellets

Precipitation in the form of ice pellets and hail is of importance to the aviation world even though the occurrence of each of these precipitation is rare. To develop algorithms that will identify these precipitation forms demands that a number of such episodes occur at the site of a present weather sensor to obtain a sufficient data base of particle size/velocity distributions for analysis.

The occurrence of ice pellets alone, unaccompanied by snow or rain, seems to be a rarity at Otis ANGB. During the winters of 1986/1987 and 1987/1988, human observers at the AFGL WTF and/or the Otis FAA control tower reported ice pellets (IP) during some precipitation episodes, but always accompanied by rain or snow. The ice pellets invariably occurred when a changeover from rain to snow or vice versa occurred. No attempt was made here because of the mixed forms of the precipitation, to develop algorithms for the identification of ice pellets. The occurrence of hail at a particular site is in general a very rare occurrence.

Hail occurred once at Otis ANGB during the three year time period that HSS Inc present weather sensors were there. However, the AFGL-WTF data collection system was not operating at the time so that there is zero data base to work with. Early in the present program a tentative plan was formulated to simulate hail by dropping small cubes of ice through the sample volume from a tower of sufficient height to provide the terminal velocity of the simulated hail.

Experts on hail were contacted for advice on how best to simulate the optical scattering properties of hail. The response was as stated above: i.e., small cubes of ice would provide representative samples of hail for our purposes.

Again, because of the press of the more important program objectives, the simulation of hail was never carried out.

2.3.1.6 Improve Rainrate Measurement Accuracy

Measurement of rainrate, or snowfall rate, is easily accomplished by the HSS Inc types of present weather sensors since they measure the size of each particle passing through their sample volume.

In the case of rain, the amount of water falling during the sample time period, typically one minute, is calculated by the on-board microprocessor based on the number and sizes of raindrops that were recorded during the sample time period.

A straightforward calculation of the amount of water falling through the sample volume, based only on the number and size of the raindrops has an inherent error. The ellipsoioal shape of the sample volume and the distribution of the source illumination within the sample volume introduces a bias to the rainfall measurement which must be compensated for by a calibration. For example, raindrops of the same size falling through different parts of the sample volume can appear to have slightly different sizes. An empirical calibration constant is found by comparing rainfall accumulation measurements made by a prototype present weather sensor with rainfall accumulation measurements made by a conventional rain gauge, usually a tipping bucket rain gauge. The comparison is made for a number of rain episodes and the calibration constant adjusted until good agreement is reached. The calibration constant thus arrived at using a single prototype present weather sensor suffices for all other present weather sensors of identical characteristics.

Previous in-house tests of the accuracy of the rainrate measurements made by the HSS Inc Present Weather Sensors (Reference 1) had shown a measurement accuracy of 7 percent. During those tests, HSS Inc discovered what most meteorologists already know: that there is no ideal rain gauge for use as a reference standard. Rain gauges are subject to the vagaries of: wind effects, freezing, evaporation, too slow a rainrate and too fast a rainrate.

During the years 1986 and 1987 when HSS Inc Present Weather Sensors were under either formal or in-house tests at the AFGL-WTF, a single heated tipping bucket rain gauge was the only reference standard collocated with the Present Weather Sensors. A second tipping bucket was located several hundred feet away from the sensor test area. It, however, often gave readings that were inconsistent with the reference gauge. At times the readings of the two gauges differed by as much as a factor of two.

For the winter 1987/1988 test program, an experimental weighing-tipping rain gauge was installed by AFGL which proved to be a more reliable reference standard although there were times when it also had problems. This experimental gauge is more sensitive than the tipping bucket rain gauges. One of its problems occurs during very

light rainfall. Before it registers any rainfall, its surfaces must be wetted. Often times there is a lag between when the HSS Inc Present Weather Sensors first report precipitation and the experimental weighing-tipping rain gauge first reports precipitation.

2.3.2 Desirable Software Upgrades

2.3.2.1 Identify Dust and Smoke

Dust, smoke and fog are indistinguishable by their extinction coefficients alone. When the atmospheric extinction coefficient approaches or exceeds 1.5 km^{-1} the obstruction to vision can almost certainly be attributed to one of these sources. Invariably, the obstruction to vision at high extinction coefficients is fog, but not always. The ability to distinguish between them could be important, especially for remotely operated present weather sensors.

Presently, the HSS Inc present weather sensors report only fog or haze as obstructions to vision. According to the International Visibility Code, the borderline between fog and haze is 1.5 km^{-1}; higher extinction coefficients representing fog, lower represent haze. A different dividing line, 0.62 km^{-1}, is used in the HSS Inc sensors. Also, haze is only reported when the extinction coefficient lies between 0.62 km^{-1} and 0.27 km^{-1} (daytime visual ranges of 3.0 and 7.0 miles respectively).

The choice of the extinction coefficient that defines the separation between fog and haze was made somewhat arbitrarily for the HSS Inc present weather sensors. Here in the U.S. many weather observers choose to report fog if the obstruction to vision limits the visibility to less than six miles. We chose to fix the separation between fog and haze at a three mile daytime visual range, nearly midway between six miles and the International Visibility Code value of 2 kilometers or 1.24 miles.

One convention sometimes used by the National Weather Service for automatically distinguishing fog from haze uses the value of relative humidity and the temperature-dewpoint spread. If the relative humidity is greater than 50% and the temperature-dewpoint spread is greater than or equal to 4 degrees, then the obstruction to vision is haze. If the relative humidity is greater than 50% and the spread is less than 4 degrees, then the obstruction to vision is fog. In addition, when the relative humidity is less than 50% and the visual range is less than 7 miles (11.3 km), then the obstruction to vision is smoke.

One of the desirable goals of the present program was to implement the foregoing depoint spread conventional by installing a relative humidity sensor on-board each present weather instrument. The humidity sensor would be near the on-board temperature sensor which is situated at the bottom of the power/control unit.

Modifications to the on-board microprocessor software would be made to implement the necessary algorithms. This phase of the program was never accomplished because of the need to achieve the higher priority goals of the program.

Two comments are in order here regarding this particular subject.

First, as the automation of weather reporting progresses it would be helpful, and seemingly important, to have a standardized definition of fog here in the United States, in terms of its atmospheric extinction coefficient.

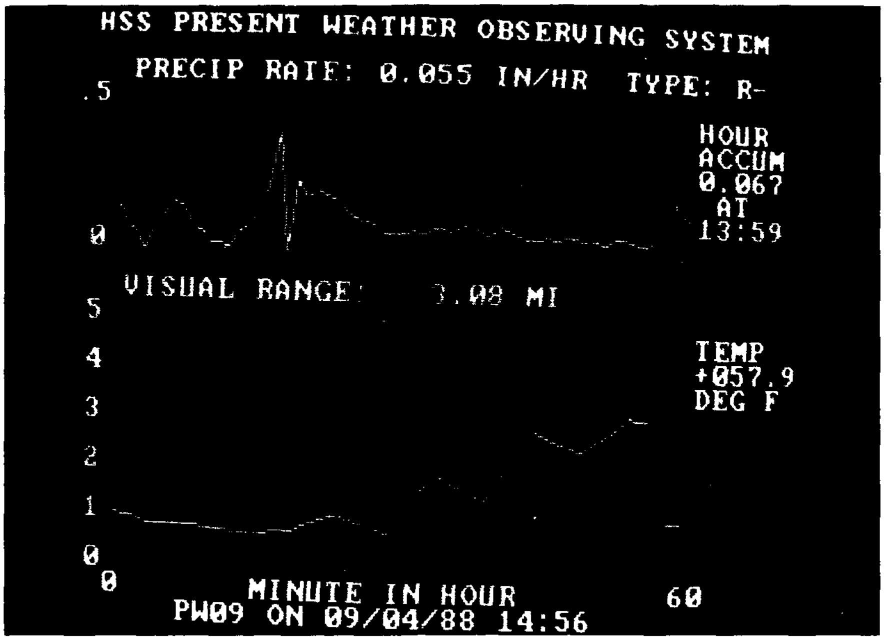
Secondly, the addition of a backscatter receiver to the HSS Inc Present Weather Sensors opened up another possible way of distinguishing fog from smoke or dust. This possibility became obvious during experiments with the prototype backscatter receiver first installed on a present weather sensor. Preliminary evidence clearly established a difference between the forwardscatter/backscatter ratio for fog versus the same ratio for smoke. Time did not permit further pursuit or exploitation of this technique as a means for distinguishing between fog and smoke or dust.

2.3.2.2 Video Graphics Display

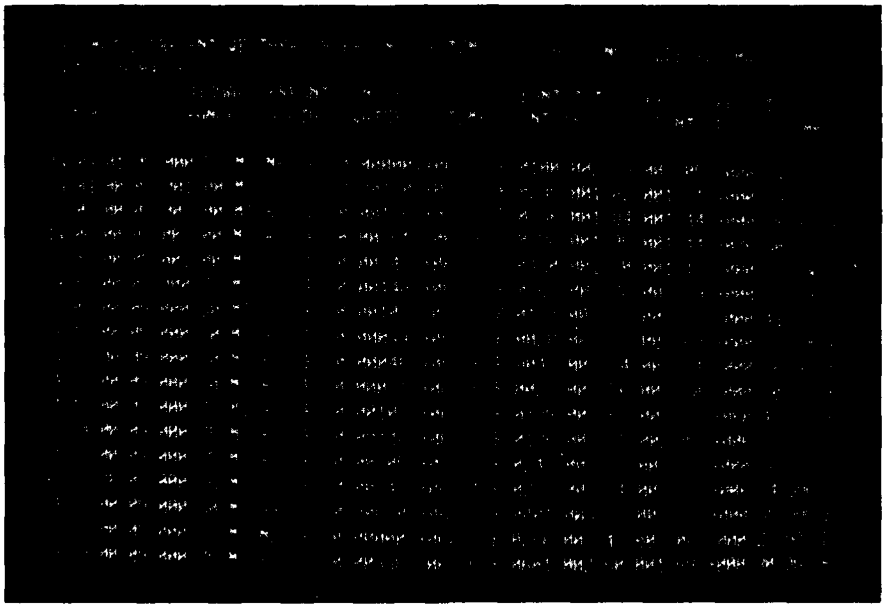
Until recently the only real-time video display of the present weather sensor measurements was a tabular display at the control computer of infoer/operator an instantaneous picture of the action that has taken place over a period of time. It does not require scanning long sequences of numbers to digest what has happened in the last hour or more. For that reason, a desirable goal of the present program was to develop a graphics software program as an alternative way of displaying the present weather sensor data.

Such a program was written for use on IBM Personal Computers (or any of its clones). Examples of the graphics display and the corresponding tabular displays are shown in Figures 2.4 through 2.7. The tabular displays provide seventeen minute sequences of reporting information while the graphics displays provide one-hour segments of data. The now-time cursor in the graphics display is the leading edge of the two-minute gap in the visual range and rainrate displays. A legend of symbols and abbreviations used in the two display forms is provided in Table 2.4.

A change from one type of display to the other can be made with the touch of a function key on the control computer keyboard. A second software program was developed to permit scrolling through archived data while viewing the graphics display. For example, twenty-four hours of the graphics display can be reviewed in a few minutes.

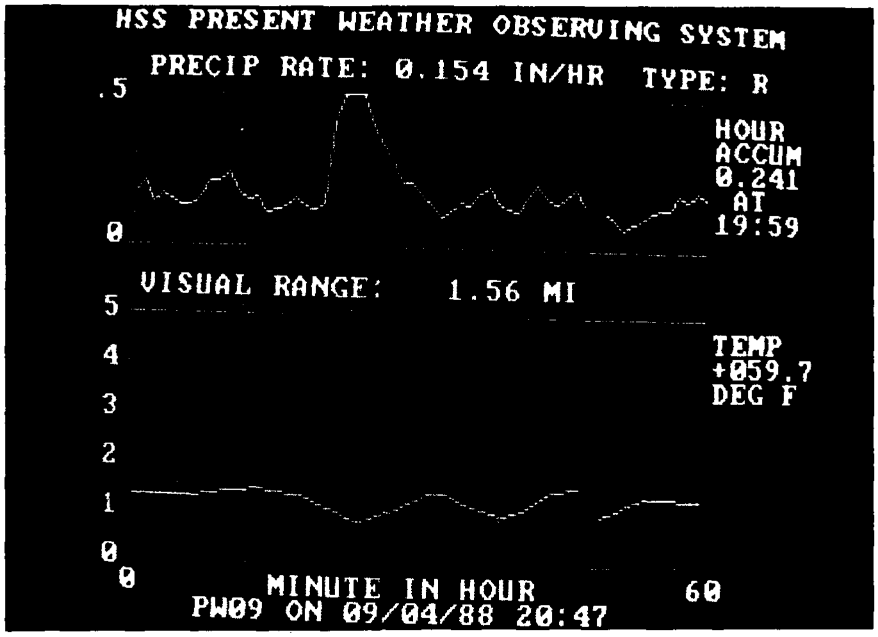


(a) Graphics Display : 13:58–14:56

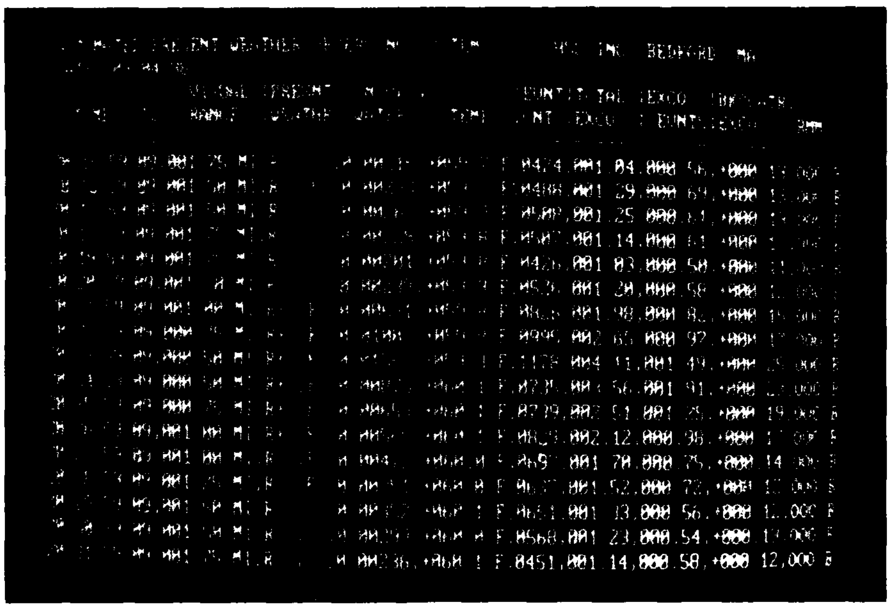


(b) Tabular Display : 14:03–14:19

FIGURE :2.4.Real–Time Displays of Present Weather Data : 4 September 1988.

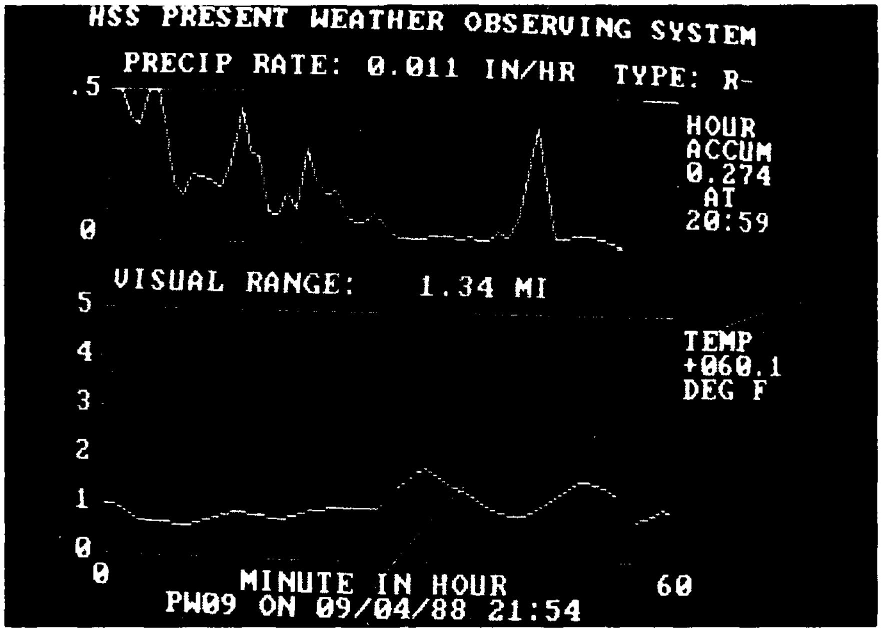


(a) Graphics Display : 19:49–20:47

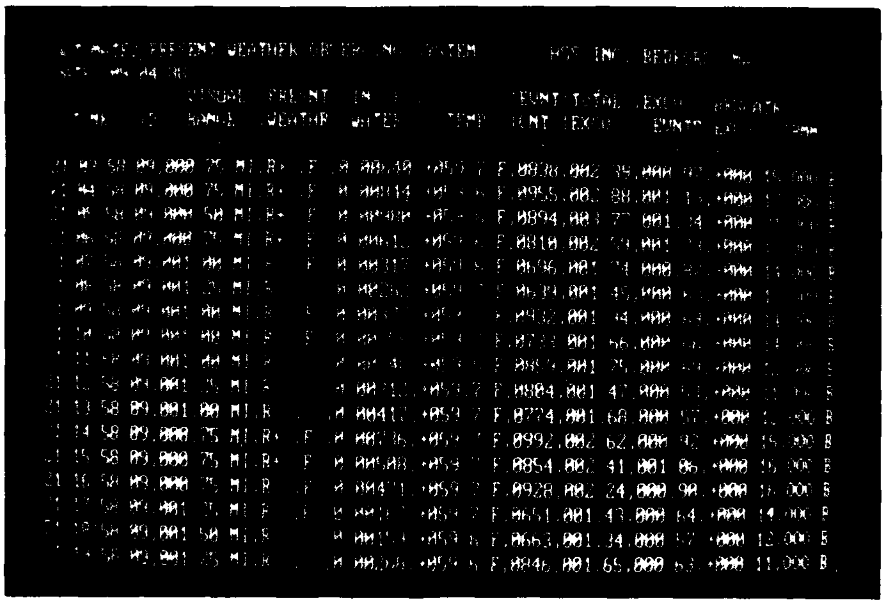


(b) Tabular Display : 20:16–20:32

FIGURE : 2.5. Real-Time Displays of Present Weather Data : 4 September 1988.

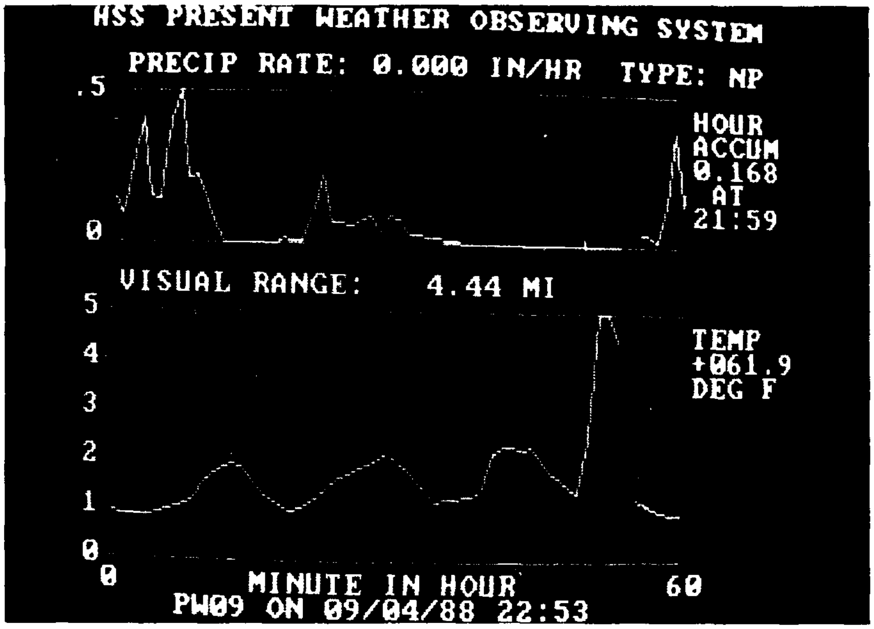


(a) Graphics Display : 20:56–21:54

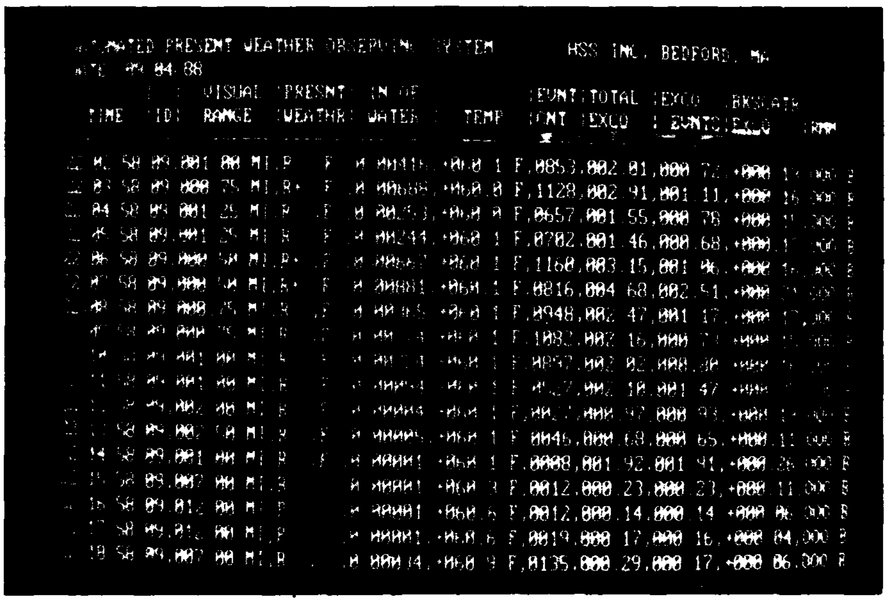


(b) Tabular Display : 21:04–21:20

FIGURE : 2.6. Real-Time Displays of Present Weather Data : 4 September 1988.



(a) Graphics Display : 21:55–22:53



(b) Tabular Display : 22:03–22:19

FIGURE :2.7. Real-Time Displays of Present Weather Data : 4 September 1988.

Table 2.4. Legend of Symbols and Abbreviations used in the Graphics and Tabular Displays of the HSS Inc Present Weather Sensors.

GRAPHICS DISPLAY LEGEND

UPPER GRAPHIC DISPLAY : Past One Hour of Rain Rate (Inches / Hour)

LOWER GRAPHIC DISPLAY : Past One Hour of Visual Range (Miles)

PRESENT TIME CURSER : Two-Minute Break in One-Hour Displays

PRESENT TIME VALUES : (1) Visual Range (Miles)
(2) Precipitation Rate (Inches / Hour of H_2O)
(3) Precipitation Type
(4) Ambient Temperature

PRECIPITATION ACCUMULATION : Total H_2O Accumulated in Last Hour Ending on the Hour

TABULAR DISPLAY LEGEND

COLUMN	ABBRIEVIATION	DESCRIPTION
1	TIME	Hour : Minute : Second
2	ID	Instrument ID No.
3	VISUAL RANGE	Visibility in Miles (ASOS,AWOS Rpt. Increment)
4	PRESENT WEATHER	Precipitation Type / Intensity L-, L, L+ (Drizzle) R-, R, R+ (Rain) S-, S, S+ (Snow) P-, P, P+ (Unidentified Precip.) Obstruction to Vision F (Fog) H (Haze)
5	IN.OF WATER	H_2O in Last Minute (in Inches)
6	TEMP.	Temperature,Degrees F
7	EVNT CNT	Numbers of Particles Passing thru Sample Volume in Last Minute
8	TOTAL EXCO	Total Atmospheric Extinction Coefficient (1 / km.)
9	EXCO-EVENTS	Total EXCO minus Particle EXCO (1 / km)
10	BKSTR.EXCO	Scattering Coefficient at 110 degrees (1 / km.)
11	RMM	Remote Maintenance Monitoring Indicators

The scrolling can be stopped or started with the touch of a key should the operator desire to examine a particular time interval.

The amplitude scales of the graphics display (i.e., rainrate and visual range) are changeable by manual instructions to the program. Automatic scale changes are highly desirable, but were not implemented under the present program.

2.3.2.3 Identify Mixed Precipitation

An attempt was made during the winter and spring of the 1986/1987 test program to identify mixed forms of precipitation. Two symbols, MRS and MSR representing mixed forms of precipitation were added to the conventional list of precipitation symbols. The symbol MRS was used to indicate mixed rain and frozen precipitation with the rain component dominating the frozen component. The symbol MSR symbolized the reverse form of mixed precipitation; i.e., the frozen precipitation component dominating the rain component.

The mixed precipitation identification algorithms were based on a minor amount of data; actually a single episode that occurred in December 1986 at HSS Inc prior to shipment of sensors to their test destinations at Otis ANGB and Sterling, VA.

The algorithms were installed in several sensors. Results were not encouraging so that eventually they were removed from all sensors in which they had been installed.

The backscatter receiver channel provides additional information which, we believe, can aid significantly in identifying forms of mixed precipitation. This belief is somewhat substantiated by an examination of data obtained by sensor PW-04 during mixed precipitation episodes in the winter 1987/1988 test program at Otis ANGB. For lack of time, the further pursuit of mixed precipitation identification algorithms was not pursued.

2.3.2.4 Measure Snow Particle Densities

In the earlier present weather sensor development program (Reference 1), it was demonstrated that the amount of snowfall (i.e., H_2O equivalent) was measurable to an accuracy of 20 percent using the simple assumption that snow particles have a density of one-tenth that of raindrops. Snowfall amount is determined with an HSS Inc present weather type of sensor by first sizing the particles; i.e., using the amplitude of the signal generated as the particle passes through the sample volume to place it in

a size bin in the precipitation identification matrix. Secondly, if the identification algorithms identify the form of precipitation as being snow, a density factor is applied during the calculation of the amount of water in each size bin. The density factor is required because the size bins represent true sizes of raindrops and only apparent sizes of snow particles.

The assumption of a density of one-tenth for particles of snow proved to be reasonable for some forms of snow; e.g., snowflakes and light powered forms. Obviously, however, it is not a valid assumption for all forms of frozen precipitation.

A desirable goal of the present contract was to devise sensor algorithms, which would identify several basic forms of frozen precipitation, and to determine the density factors corresponding to those basic forms. Very little effort was directed toward this goal. Achievement of the higher priority goals took precedent, plus there was a gradual acknowledgment that there was insufficient information in the precipitation recognition matrices to identify the various forms of frozen precipitation.

As in the case of mixed precipitation forms, there is now a belief that the additional information provided by the backscatter receiver channel, will permit the development of algorithms that will identify several basic forms of precipitation. When that task is undertaken, it will require the presence of a human observer capable of identifying the basic groups of frozen precipitation having similar density factors; e.g., (1) plates and stellars, (2) columns and needles, (3) spatial dendrites, capped columns and irregular crystals, (4) graupel, and (5) ice pellets. It will also require an accurate heated rain gauge to measure the equivalent amount of water in a snowfall episode, or portion thereof. Many forms of frozen precipitation may fall in any one snowstorm, thus placing exacting demands both on the observer and on the rain gauge.

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3.0 SENSOR PERFORMANCE

3.1 Winter 1986/1987 Tests

Sensors PW-01 through PW-04 were located at Otis ANGB during the winter 1986/1987. Sensor PW-05 was located at the NWS Sterling, VA test site for most of the winter and then moved to Johnstown, PA toward late winter. Because of its elevation, snow episodes can be expected to occur into early spring at Johnstown.

HSS Inc did not receive a sufficient amount of data from the test organizations to conduct a meaningful evaluation of its sensors performance during the winter 1986/1987 test period. Therefore, we shall provide here the performance evaluation conducted by the two test organizations: the NWS at the Sterling, VA and Johnstown, PA test sites, and the DOT at the Otis ANGB (see Reference 6). The only editing of their results has been to strike most references to figures and tables which have not been included here, and to add the word "sensor" after their designator HSS.

3.1.1 Sterling and Otis Sites

3.1.1.1 Precipitation Detection and False Alarms

"The HSS sensor was tested during 105.77 hours of precipitation occurrence at the Sterling and Johnstown test sites. The HSS sensor correctly detected precipitation with minute-by-minute human observations 98% of the time. A detection accuracy rate of 97% was recorded during 27.27 hours of rain occurrence and 98% during 76.1 hours of snow occurrences. As previously shown, the HSS sensor accurately detected the beginning of precipitation occurrences. In fact, the sensor began a snow event in advance of the human's observation by 2 minutes. It was, therefore, concluded that HSS surpasses the ASOS detection requirements, as it reports an occurrence when the precipitation rate-of-fall is less than 0.01 in/hr (0.25 mm/hr). HSS detection was so sensitive that it appeared to report precipitation even if only a few snowflakes or raindrops fell through its sample volume. This sensitivity to particles in its sample volume, although advantageous to very accurate precipitation detection, did cause problems in falsely indicating precipitation occurrence during blowing snow. An example of this was during a snow event at Sterling on 01/23/87. The HSS sensor accurately detected over 10 hours of snow occurrences. However, when the snow ended and increased wind produced blowing snow, the HSS sensor continued to indicate light snow. Similar detection false alarms in blowing snow were seen in Johnstown."

"The HSS recorded an overall false alarm rate of less than 0.2% during a relatively short time period of no precipitation (1127.5 hours). The HSS, therefore, meets the ASOS false alarm rate requirements."

Authors' Comment: A point sensor cannot distinguish blowing snow from falling snow. We question whether the detection of blowing snow should be considered a false alarm.

3.1.1.2 Precipitation Identification

"The HSS sensor exceeded the ASOS differentiation requirements for solid precipitation by correctly reporting snow 98% of the time, and it was correctly reported or reported as a 'mixed state' or 'P' 100% of the time. However, the HSS sensor had much difficulty correctly reporting liquid precipitation as such. In the 26.17 hours of liquid precipitation only detection, the HSS sensor correctly reported liquid precipitation only 42% of the time, and it was correctly reported or reported as 'mixed state' or 'P' 52% of the time. This differentiation problem is illustrated in detail in Table 3-6 (not shown here) when the human reported 'SG-' changing to R- but the HSS sensor maintained a 'S-' report."

3.1.1.3 Precipitation Accumulation

"A minimal amount of data was accumulated prior to the test report to compare the HSS sensor generated rain accumulations with standard rain gauge measurements. From the three daily totals, the HSS generated rain accumulation averaged within 2.43 mm of the NWS standard. The maximum difference between the HSS and standard was 4.66 mm and the minimum was 1.04 mm. In all of the comparisons, the HSS accumulation value was less than that of the standard rain gauge."

"Comparison of water equivalent accumulations during snow events by the HSS sensor and the human observer were conducted during 2 events at Johnstown. Wind accompanying the snowfall made such measurements difficult. Such comparisons at Johnstown show the HSS Inc continually indicating less snow than that recorded manually."

"Further testing is recommended to adequately compare the HSS generated rain and water equivalent accumulations."

3.1.1.4 Precipitation Intensities

"The set of measurements (hourly rates) analyzed to evaluate the HSS sensor performance in comparison to the ASOS precipitation rate requirement was relatively small and the sensor did not compare well with the standard rain gauge in this limited data set. A much larger set of comparison measurements is needed to properly evaluate the precipitation rate requirement."

"For additional information, comparison matrices of minute-by-minute human observations vs. HSS sensor observations of precipitation intensities were made. The HSS sensor reported liquid precipitation intensities within one intensity category of the human observation 100% of the time. The HSS sensor reports snow intensities within one intensity category of the human reports 97.7% of the time. No reporting tendency is obvious."

3.1.1.5 Field Performance

"The HSS sensor operated continuously for approximately 3 months in a wide range of environmental conditions without component failure. Wind vibration did not affect the sensor or its mounting. Some accumulation of snow in the sensor's hood did affect its snow intensity output, but did not cause complete sensor failure."

3.1.2 Otis, MA Test Site

3.1.2.1 Precipitation Detection

"The HSS sensors were tested during a combined 180.88 hours of precipitation occurrence at the Otis, MA Test Site. The sensors recorded detection rates (with human observers) of 96-100% in snow, 86%-96% in rain/drizzle, and 100% in ice pellets for 3 of the sensors (PW-01 recorded a 60% rate for ice pellets.)"

3.1.2.2 Precipitation Identification

"During the small amount of snow occurrence recorded at the test site (less than 3 hours per sensor), the sensors failed to meet the ASOS snow differentiation requirements, although a few sensors did come close. The HSS sensors correctly reported snow as snow (and not as rain or 'mixed') over a wide range of values (60-100% of the time) and correctly report snow as snow or as a 'mixed state' 66-100% of the time. Again,

the sample size of snow test data is very small and could, therefore, be classified inconclusive, and undoubtedly contributed to the wide range of differentiation rates among the sensors."

"Only HSS PW-01 sensor met or nearly met (within 1%) the ASOS liquid differentiation requirements. This sensor correctly reported liquid as liquid (and not snow of 'mixed state') or as a 'mixed state' 98% of the time. The remaining three sensors correctly reported liquid precipitation from 60%-75% of the time, and reported liquid correctly or as a 'mixed state' from 88%-90% of the time. These correct rates do not meet the ASOS requirements."

3.1.2.3 Precipitation Accumulation

"Precipitation accumulation/rate occurrences of three HSS sensors (PW-01 doesn't accumulate rain) were evaluated. Table 3-24 (not shown here) shows the correction factors for the HSS sensors. As seen, the HSS sensors required smaller correction factors than the STI sensors. The crooked HSS plots resulted from the mistaken identification of rain as snow by the HSS sensors, which then results in the sensor calculating only one-tenth the liquid water content as rain for the same number and size of particles. The HSS sensors give a straight-line comparison whenever they correctly identify the precipitation type."

3.1.2.4 Precipitation Intensities

"Comparison matrices of minute-by-minute human observations and sensor reports of precipitation intensities were made. All HSS sensors reported precipitation intensities within one category 88%-100% of the time."

3.1.2.5 Field Performance

"The HSS sensors operated continuously at the test site during a wide range of environmental conditions with no component failures or alignment problems. The sensors did, however, experience failure due to snow-clogged lenses during two blizzards at Otis. The lens' heaters were apparently overwhelmed during the blizzard's extreme conditions, but they were able to clean the lenses after the conditions had improved. The HSS sensors were clear of snow-clogging during other less-severe snow events."

3.2 Winter 1987/1988 Tests

During the winter 1987/1988, the HSS Inc type of present weather sensors involved in test programs were disbursed to several locations as shown in Table 2.2. PW-01, PW-02, PW-04, PW-09, and PW-11 were situated at the Otis ANGB where the DOT conducted a Present Weather Sensor performance evaluation test program sponsored by the NWS and FAA. PW-05 was installed at Fairbanks, Alaska by the NWS to evaluate its capability to detect small ice crystals that are not an uncommon atmospheric phenomenon in that region. PW-03 was installed at the Worcester, MA airport where a performance evaluation of freezing precipitation sensors was also conducted by the DOT. The PW-03 itself was not under test; it was being utilized for its capability to detect the onset and presence of precipitation at an unmanned test location. Two other sensors PW-07 and PW-10 did not participate in any test programs.

At Otis ANGB, the present weather sensor data was collected by a DOT data acquisition system that utilized a PDP-11/23+ computer. After the test program was over, HSS Inc was furnished disks of data from which to conduct a performance evaluation of the HSS Inc sensors over the duration of the test program. Small amounts of data were furnished during the course of test program so that HSS Inc could conduct a snapshot performance analysis of the sensors.

The performance analysis presented here was conducted on three Model PW-402A operational type sensors; namely, PW-04, PW-09, and PW-11. The limited number of data channels on the DOT data acquisition system excluded PW-01 from the test program, and PW-02 was returned to HSS Inc midway during the test program to correct an electronic failure; it was never returned to the test site, rather it was installed at AFGL for demonstration of present weather sensor capabilities.

No information on the performance of the PW-05 sensor at Fairbanks, Alaska is yet available, so that none is included in this report.

3.2.1 Precipitation Detection and False Alarms

3.2.1.1. Detection

The onset of precipitation provides the best opportunity to evaluate the precipitation detection capability of present weather sensors. The only drawback to

that approach is the obvious necessity for a human observer to be present at the start of a precipitation episode. During the five months of sensor performance evaluation at the AFGL-WTF, a human observer was present only three times when precipitation episodes started. The AFGL-WTF did not have 24 hr. observer coverage; rather an on-call observer was posted just before or after an episode started. A full-time observer was present at the Otis Air Traffic Control Tower, which is located nearly a mile away. Their observations, therefore, were not adequate to evaluate sensor detection capability.

Examples of the precipitation detection capability of HSS Inc present weather sensors are illustrated in Table 3.1, where a comparison is made with human observations at the onset of precipitation for the three episodes where data is available.

The present weather sensors invariably indicate the onset of precipitation within a few minutes of the human observer, and in one case (16 March), two of the sensors detected precipitation prior to the human observer.

Measurements by the weighing rain gauge are shown for each episode. the units of measurement are 1/10,000 of an inch. Negative values are indicative, we understand, of high wind conditions not precipitation. For example, the first indication of rain by the weighing rain gauge during the 20 February episode occurred at 14 minutes after onset of precipitation.

3.2.1.2 False Alarms

The procedure for determining the false alarm rate of the present weather sensors was straightforward. First, the total number of reporting periods (minutes) that the DOT data acquisition system was functional and provided reports during a given month was established for each sensor as shown in Tables 3.2, 3.3 and 3.4.

Next, the number of reporting periods during which precipitation was actually detected by a given sensor was established. In this case, the sensor detection reports themselves were used to establish the true occurrences of precipitation, with the proviso that the Otis tower observer must have also reported precipitation within ten minutes of the sensors detection report.

The sample data base for false alarms was then found by subtracting the number of minutes for which true precipitation occurrences were reported from the total number of operating minutes of the data acquisition system.

Table 3.1. Onset of Precipitation as indicated by the AFGL-WTF Observer, the Weighing Rain Gauge and three HSS Inc Present Weather Sensors, for three Precipitation Episodes.

DATE : 12 Febuary 1988

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
WTF OBS	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--	S--
PW-04							P-	P-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-
PW-09			P-	P-	P-	P-	P-	P	P	R	R+	R	R+	R	P	P	R+	R+	R+	P	P
PW-11					S-	S-	P-	P-	P-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-
WRG IN X 10^4			0	-.1	0	-.2	.1	0	0	0	-.1	0	0	-.1	0	0	.2	-.2	0	0	0

Elapsed Time (Minutes)

DATE : 20 Febuary 1988

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
WTF OBS.	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--	R--
PW-04		P-	P-	P-	R-	R-	R-	R-	R-	R-	P	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-
PW-09		P-	P-	P-	P-	R-	R-	R-	R-	R-	R-	R-	P-	R-	R-	P-	R-	R-	R-	R-	R-
PW-11		P-	P-	P-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-	R-
WRG IN X 10^4		0	-.1	0	0	0	-.1	0	0	0	0	0	-.1	0	.4	0	0	-.1	0	-.1	0

Elapsed Time (Minutes)

DATE : 16 March 1988

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
WTF OBS.				S--	S--	S--	S-	S-	S- R--	S- R--	S- R--	S-R-	S-- R--	S-- R--	S-- R--	S-- R--	R--	R--	R--	NP	NP
PW-04		P-			P-	P-	S-	S-	S-	S-	S-	S-	S-	S-	S-	P	P	P	NP	P-	S-
PW-09	S-	S-			S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	S-	P	P	P	P	P	P
PW-11					P-	P-	R-	R-	R	R+	R	R-	R-	P	R-	P	P	P	NP	P	P
WRG IN X 10^4	0	0	0	0	0	0	0	0	2 6	20.0	12.9	5.2	2.4	1.9	0.9	1.0	0.7	0.4	0.2	0	0.2

Elapsed Time (Minutes)

TABLE: 3.2. Precipitation False Alarm Analysis:
Summary of Results for PW-04

TIME PERIOD: 2 FEBRUARY - 9 JUNE 1988

THRESHOLD LEVEL: 0.00001 in/min

SAMPLE TIME PERIOD: one minute

INSTRUMENT: PW-04

MONTH	DATA LOGGER OPERATING (min)	PRECIPITATION OCCURRING (min)	SAMPLE DATA BASE (min)	FALSE ALARMS (min)
FEBRUARY	23279	6162	17105	46
MARCH	25341	4858	20483	10
APRIL	30468	6859	23609	21
MAY	12233	5559	6674	0
JUNE	4776	20	4756	0
TOTALS:	96097	23458	72627	77

FALSE ALARM RATE = (FALSE ALARMS)/(SAMPLE DATA BASE)

= 77/72627 = 0.00106

TABLE: 3.3. Precipitation False Alarm Analysis: Summary of Results for PW-09

TIME PERIOD: 28 JANUARY - 9 JUNE 1988

THRESHOLD LEVEL: 0.00001 in/min

SAMPLE TIME PERIOD: one minute

INSTRUMENT: PW-09

MONTH	DATA LOGGER OPERATING (min)	PRECIPITATION OCCURRING (min)	SAMPLE DATA BASE (min)	FALSE ALARMS (min)
JANUARY	1762	0	1762	0
FEBRUARY	26892	6334	19818	12
MARCH	25341	4858	20483	15
APRIL	30468	6859	23609	6
MAY	12233	5559	6674	0
JUNE	4776	20	4756	0
TOTALS:	101472	23630	77102	33

FALSE ALARM RATE = (FALSE ALARMS)/(SAMPLE DATA BASE)

= 33/77102 = 0.00043

TABLE: 3.4. Precipitation False Alarm Analysis: Summary of Results for PW-11

TIME PERIOD: 28 JANUARY - 9 JUNE 1988

THRESHOLD LEVEL: 0.00001 in/min

SAMPLE TIME PERIOD: one minute

INSTRUMENT: PW-11

MONTH	DATA LOGGER OPERATING (min)	PRECIPITATION OCCURRING (min)	SAMPLE DATA BASE (min)	FALSE ALARMS (min)
JANUARY	1762	0	1762	0
FEBRUARY	27361	6322	20216	80
MARCH	25341	4858	20483	12
APRIL	30468	6859	23609	5
MAY	12233	5559	6674	13
JUNE	---	--	--	--
TOTALS:	97165	23598	72744	110

FALSE ALARM RATE = (FALSE ALARMS)/(SAMPLE DATA BASE)

= 110/72744 = 0.00151

The monthly data base for potential false alarms is given in column four of each table. The number of actual false alarms reported in any given month is given in column five. The false alarm rate for each sensor was calculated by dividing the total number of false alarms by the total number of minutes in the data base.

For two of the sensors, PW-04 and PW-11, the majority of false alarms occurred during one brief period in February, and were traced to sunglints from windshields of automobiles parked nearby. These sensors were re-oriented slightly as described in Section 2.3.1.4 and the false alarms ceased. The cause of the other false alarm occurrences was never established.

3.2.2 Precipitation Identification

3.2.2.1 Data Base

The test data furnished to HSS Inc covered the time period from late January through early June. The occurrences of precipitation during that time period were treated as 77 separate episodes. In four instances, a changeover from rain to snow or vice versa occurred. The precipitation before the changeover was treated as a separate episode from the precipitation which occurred after the changeover. No attempt was made to evaluate the performance during the brief periods of mixed precipitation between changeovers. Thus, the data base for evaluating the precipitation identification capabilities of the sensors consisted entirely of snow or rain episodes as shown in Table 3.5. The true identity of the precipitation was established using the AFGL-WTF human observations when that observer was present or the Otis tower observations when he was not.

3.2.2.2 Sensor Performance

The performance of each sensor was evaluated using three detection thresholds: 0.01, 0.005, and 0.0025 inches per hour of water for rain episodes, or equivalent water content for snow episodes. Precipitation amounts were determined from the minute-by-minute reports of each sensor.

Table 3.6 shows the performance of sensor PW-04 for rain episodes. This analysis demonstrates that sensor PW-04 meets the ASOS rain identification requirements at threshold levels of 0.01 and 0.005 inches per hour and falls just a little short at a threshold of 0.0025 inches per hour.

Table 3.7 shows the performance of sensor PW-04 for snow episodes.

TABLE: 3.5. Data Base for the Precipitation Identification Permformance Analysis

DATE	TIME PERIOD	EPISODE TYPE	HUMAN OBSERVER OTIS TOWER	HUMAN OBSERVER AFGL WTF	COMMENTS
2/2/88	16:11-23:59	R	R-F	R-	
2/3/88	0:00- 1:24	R	R-F	R-F	CHANGEOVER R -> S
2/3/88	2:49- 7:16	S	S-F	S-	
2/12/88	7:33-10:40	S	S-F	S-	CHANGEOVER S -> R
2/12/88	11:21-23:59	R	R-F	R-F	
2/15/88	22:05-23:59	R	R-	---	
2/16/88	0:00- 5:11	R	R-F	---	
2/16/88	12:20-17:25	R	R-F	R-	
2/20/88	2:17-11:45	R	R-	R-	
2/24/88	3:00- 4:30	R	R-	---	
2/24/88	7:40- 8:40	R	R-F	---	CHANGEOVER R -> S
2/24/88	9:00-12:25	S	S-F	S-	
2/25/88	23:16-23:55	S	S-	---	
2/28/88	3:39- 4:28	S	SW-	---	
3/4/88	6:24- 8:35	R	R-F,L-F	R-	
3/4/88	19:20-23:59	R	R-F	---	
3/5/88	0:00- 1:23	R	R-F	---	CHANGEOVER R -> S
3/5/88	1:49- 4:14	S	IP-,S-F	---	
3/10/88	1:08- 1:29	R	R-F	---	
3/10/88	13:05-14:38	R	R-F	---	
3/14/88	12:12-15:25	S	S-F	S-	
3/15/88	2:48- 9:09	S	S-	S-,SG	
3/20/88	13:37-14:50	S	S-	S-	
3/20/88	17:59-18:25	S	SW	S-	
3/26/88	20:20-23:59	R	R-,R-F	---	
3/27/88	0:00- 2:43	R	R-,R-F	---	
3/27/88	3:11- 4:00	R	R-,R-F	---	
3/27/88	5:05- 5:27	R	L-,R-	---	

TABLE: 3.5. (cont'd) Data Base for the Precipitation Identification Permformance Analysis

DATE	TIME PERIOD	EPISODE TYPE	HUMAN OBSERVER		COMMENTS
			OTIS TOWER	AFGL WTF	
3/27/88	7:00-12:30	R	RF,R-F	---	
4/4/88	13:59-15:05	R	R-F	---	
4/4/88	15:45-17:59	R	R-F	---	
4/4/88	20:15-21:50	R	R-F	---	
4/7/88	20:40-22:46	R	L-F	---	
4/7/88	23:40-23:59	R	L-F	---	
4/8/88	0:00- 0:36	R	L-F	---	
4/8/88	6:33- 7:57	R	L-F	---	
4/8/88	15:58-20:12	R	L-F	---	
4/8/88	20:20-23:59	R	L-F,R-F	---	
4/9/88	0:01-23:59	R	L-F,R-F	---	
4/11/88	10:55-23:00	R	L-F,R-F	---	
4/12/88	2:14-17:59	R	L-	---	
4/15/88	8:45- 9:03	R	RW-	---	
4/15/88	23:00-23:58	R	RW-F,L-F	---	
4/16/88	0:01- 1:28	R	L-F	---	
4/16/88	6:54- 9:17	R	R-F	---	
4/16/88	15:38-15:58	R	RW-	---	
4/18/88	16:54-19:21	R	L-	---	
4/18/88	19:25-23:59	R	R-F	---	
4/19/88	0:01- 0:58	R	R-F	---	
4/21/88	13:26-13:49	R	R-	---	
4/23/88	20:55-21:32	R	RW-,IP-	---	
4/28/88	14:15-17:06	R	RW-,R-F	---	
4/28/88	18:28-23:30	R	R-F,RF	---	
5/6/88	15:16-15:50	R	R-F	---	
5/6/88	17:45-22:10	R	R-F	---	
5/7/88	1:05- 3:59	R	R-F	---	
5/7/88	4:00- 7:53	R	R-F	---	
5/10/88	15:06-15:58	R	RW-,R-F	---	

TABLE: 3.5. (cont'd) Data Base for the Precipitation Identification Permformance Analysis

DATE	TIME PERIOD	EPISODE TYPE	HUMAN OBSERVER		COMMENTS
			OTIS TOWER	AFGL WTF	
5/11/88	6:05- 7:59	R	R-	---	
5/11/88	8:00-11:54	R	R-	---	
5/11/88	13:20-15:59	R	RW-F	---	
5/11/88	16:00-19:48	R	R-F	---	
5/14/88	13:24-14:24	R	R-	---	
5/16/88	18:56-23:30	R	RW-F,R-	---	
5/17/88	23:51-23:21	R	RW-	---	
5/19/88	9:00-23:53	R	R-F	---	
5/20/88	0:30-11:42	R	R-F	---	
5/21/88	11:03-11:59	R	R-F,TRW-F	---	
5/21/88	12:00-13:59	R	R-F	---	
5/25/88	8:00-10:00	R	RW-F,TF	---	
5/25/88	13:27-15:59	R	R-F	---	
5/25/88	16:00-18:01	R	R-F	---	
5/25/88	20:14-23:03	R	R-F	---	
5/30/88	14:39-14:56	R	R-F	---	
5/30/88	18:00-19:29	R	RW-	---	
5/30/88	20:45-23:59	R	RW-	---	
6/9/88	12:12-23:00	R	R-,R-F	---	

TABLE: 3.6. Precipitation Identification Performance Analysis
Summary of Results for PW-04: Rain Episodes

TIME PERIOD COVERED: 2 FEBRUARY - 9 JUNE 1988
SAMPLE TIME PERIOD: one minute
LOCATION: AFGL - WTF Otis ANGB
WEATHER OBSERVERS: WTF & Otis Tower

PW—04: RAIN EPISODES

	DETECTION THRESHOLD					
	0.01 in/hr		0.005 in/hr		0.0025 in/hr	
IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL
* RAIN IDENTIFIED AS RAIN	6654	97.0%	7310	92.4%	7752	88.6%
* RAIN IDENTIFIED AS PRECIPITATION	200	2.9%	590	7.5%	992	11.3%
RAIN IDENTIFIED AS SNOW	9	0.1%	10	0.1%	10	0.1%
TOTAL NO. OF SAMPLES	6863	100.0%	7910	100.0%	8754	100.0%

* NOTE: Drizzle observations by the Observer and the Instrument are included as Rain Observations.

TABLE: 3.7. Precipitation Identification Performance Analysis
Summary of Results for PW-04: Snow Episodes

TIME PERIOD COVERED: 2 FEBRUARY - 9 JUNE 1988

SAMPLE TIME PERIOD: one minute

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: WTF & Otis Tower

PW—04: SNOW EPISODES

	DETECTION THRESHOLD					
	0.01 in/hr		0.005 in/hr		0.0025 in/hr	
IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	985	98.5%	1164	97.4%	1231	95.7%
SNOW IDENTIFIED AS PRECIPITATION	9	0.9%	25	2.1%	44	3.4%
SNOW IDENTIFIED AS RAIN	6	0.6%	6	0.5%	12	0.9%
TOTAL NO. OF SAMPLES	1000	100.0%	1195	100.0%	1287	100.0%

TABLE: 3.8. Precipitation Identification Performance Analysis
Summary of Results for PW-09: Rain Episodes

TIME PERIOD COVERED: 28 JANUARY - 9 JUNE 1988

SAMPLE TIME PERIOD: one minute

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: WTF & Otis Tower

PW—09: RAIN EPISODES

	DETECTION THRESHOLD					
	0.01 in/hr		0.005 in/hr		0.0025 in/hr	
IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL
* RAIN IDENTIFIED AS RAIN	5907	89.5%	6866	88.1%	7445	86.7%
* RAIN IDENTIFIED AS PRECIPITATION	588	8.9%	817	10.5%	1035	12.0%
RAIN IDENTIFIED AS SNOW	104	1.6%	108	1.4%	108	1.3%
TOTAL NO. OF SAMPLES	6599	100.0%	7791	100.0%	8588	100.0%

* NOTE: Drizzle observations by the Observer and the Instrument are included as Rain Observations.

TABLE: 3.9. Precipitation Identification Performance Analysis
Summary of Results for PW-09: Snow Episodes

TIME PERIOD COVERED: 28 JANUARY - 9 JUNE 1988

SAMPLE TIME PERIOD: one minute

LOCATION: AFGL - WTF Otis ANGB

WEATHER OBSERVERS: WTF & Otis Tower

PW—09: SNOW EPISODES

	DETECTION THRESHOLD					
	0.01 in/hr		0.005 in/hr		0.0025 in/hr	
IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	547	60.0%	689	63.5%	805	65.1%
SNOW IDENTIFIED AS PRECIPITATION	199	21.8%	218	20.1%	244	19.8%
SNOW IDENTIFIED AS RAIN	166	18.2%	178	16.4%	186	15.1%
TOTAL NO. OF SAMPLES	912	100.0%	1085	100.0%	1235	100.0%

TABLE: 3.10. Precipitation Identification Performance Analysis
Summary of Results for PW-11: Rain Episodes

TIME PERIOD COVERED: 28 JANUARY - 9 JUNE 1988
SAMPLE TIME PERIOD: one minute
LOCATION: AFGL - WTF Otis ANGB
WEATHER OBSERVERS: WTF & Otis Tower

PW—11: RAIN EPISODES

	DETECTION THRESHOLD					
	0.01 in/hr		0.005 in/hr		0.0025 in/hr	
IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL
* RAIN IDENTIFIED AS RAIN	6032	90.5%	6874	88.8%	7392	87.4%
* RAIN IDENTIFIED AS PRECIPITATION	622	9.3%	851	11.0%	1050	12.4%
RAIN IDENTIFIED AS SNOW	15	0.2%	17	0.2%	17	0.2%
TOTAL NO. OF SAMPLES	6669	100.0%	7742	100.0%	8459	100.0%

* NOTE: Drizzle observations by the Observer and the Instrument are included as Rain Observations.

TABLE: 3.11. Precipitation Identification Performance Analysis
Summary of Results for PW-11: Snow Episodes

TIME PERIOD COVERED: 28 JANUARY - 9 JUNE 1988
SAMPLE TIME PERIOD: one minute
LOCATION: AFGL - WTF Otis ANGB
WEATHER OBSERVERS: WTF & Otis Tower

PW—11: SNOW EPISODES

	DETECTION THRESHOLD					
	0.01 in/hr		0.005 in/hr		0.0025 in/hr	
IDENTIFICATION CATEGORY	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL	NO. SAMPLE PERIODS	FRACTION OF TOTAL
SNOW IDENTIFIED AS SNOW	344	33.3%	398	33.9%	441	35.1%
SNOW IDENTIFIED AS PRECIPITATION	346	33.5%	396	33.7%	431	34.2%
SNOW IDENTIFIED AS RAIN	343	33.2%	381	32.4%	387	30.7%
TOTAL NO. OF SAMPLES	1033	100.0%	1175	100.0%	1259	100.0%

This analysis demonstrates that sensor PW-04 also meets the snow identification requirements at threshold levels of 0.01 and 0.005 inches per hour and falls just short of meeting the requirements at a threshold of 0.0025 inches per hour.

Table 3.8 and 3.9 provide the performance analysis for sensor PW-09 in rain and snow episodes, respectively. While PW-09 essentially meets the ASOS identification requirements for rain episodes, it falls considerably short of meeting the snow identification requirements. The same situation is repeated for sensor PW-11 as is shown in Tables 3.10 and 3.11. Sensor PW-11 meets the rain identification requirements but falls considerably short of meeting the snow identification requirements.

These three performance evaluation analyses demonstrate that the backscatter receiver channel aids considerably in the precipitation identification process. It elevated the rain identification performance from just meeting the ASOS requirements as indicated by sensors PW-09 and PW-11 to well beyond the requirements as indicated by sensor PW-04; and it raised the snow identification performance from well below to well above the ASOS requirements.

The poor identification performance of sensors PW-09 and PW-11 during snow episodes is attributed to the windy conditions that invariably accompany snowstorms on Cape Cod. Sensor PW-04, with its backscatter receiver channel, is immune to the affects of wind on the precipitation identification process, for all except the very lightest of precipitation.

3.2.3 Precipitation Accumulation

Figure 3.1, in three parts, provides the rainrate history for a rain episode that occurred on 28 April 1988 at Otis ANGB. Rainrate measurements made by the AFGL weighing rain gauge and sensor PW-04 are shown. This comparison of measurements on a rainrate basis shows good agreement between the two sensors. But, because rainfall is hardly ever constant, as is illustrated in the figure, a comparison of the accuracy of sensors on a rainrate basis is difficult. An easier method of judging the accuracy of a rain gauge is to compare its rainfall accumulation measurements with those of a reference rain gauge for all or a significant fraction of a rain episode.

Rain accumulation measurements for the 28 April 1988 episode are shown in Figure 3.2, again in three parts. These plots show the final accumulation values for all three present weather sensors plus the weighing rain gauge and a tipping bucket rain gauge.

For this episode, the final accumulation measurement of sensor PW-04 agrees with that of the weighing rain gauge within a few percent. The accumulation measurements of sensors, PW-09 and PW-11 differ by greater amounts while the tipping bucket reads only one-half the amount of the weighing rain gauge.

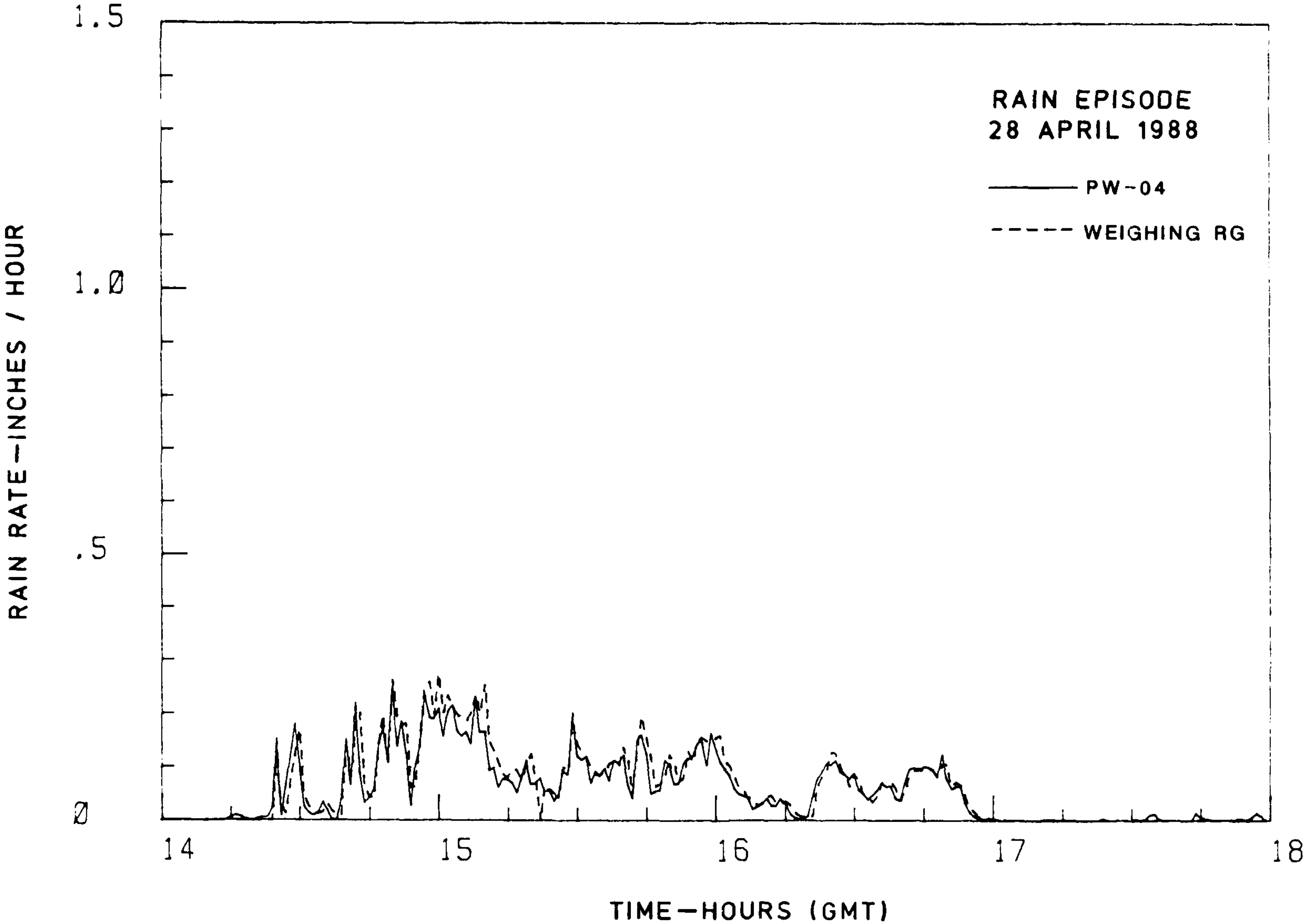

Figure 3.1 (a). Rainrate measurements by Sensor PW-04 and the AFGL weighing rain gauge (14:00 - 18:00)

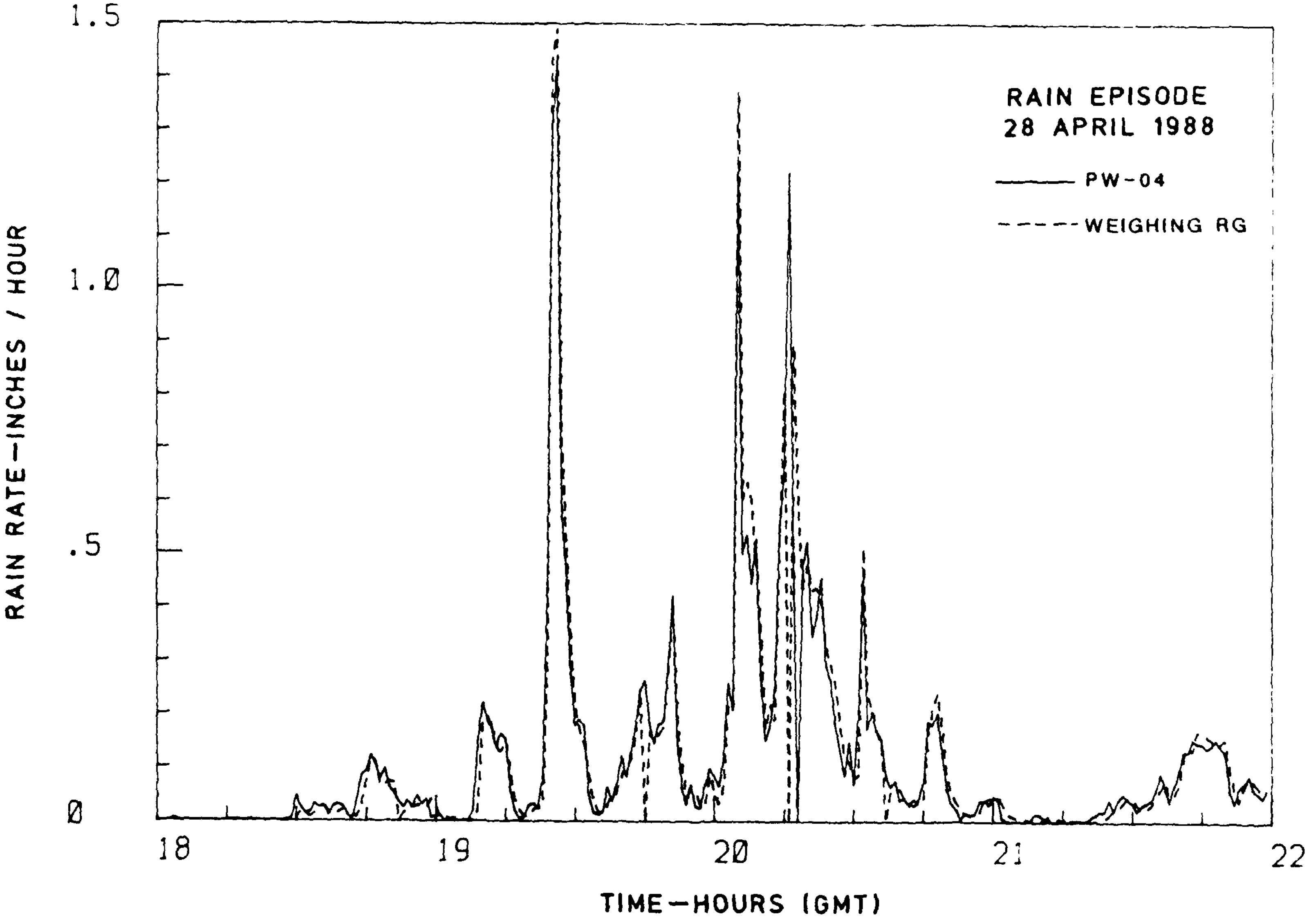

Figure 3.1 (b). Rainrate measurements by Sensor PW-04 and the AFGL weighing rain gauge (18:00 - 22:00).

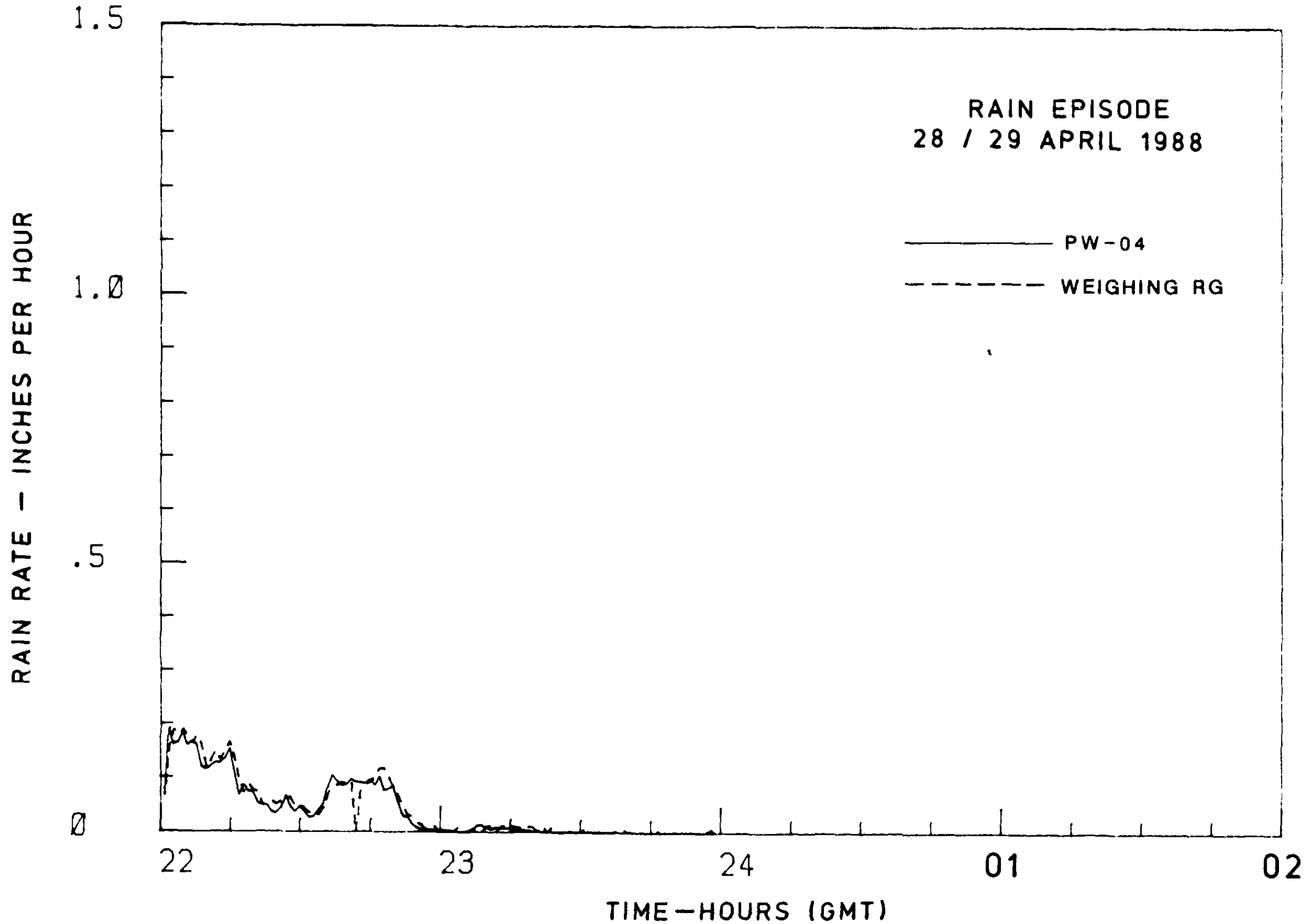

Figure 3.1 (c). Rainrate measurements by Sensor PW-04 and the AFGL weighing rain gauge (22:00 - 24:00).

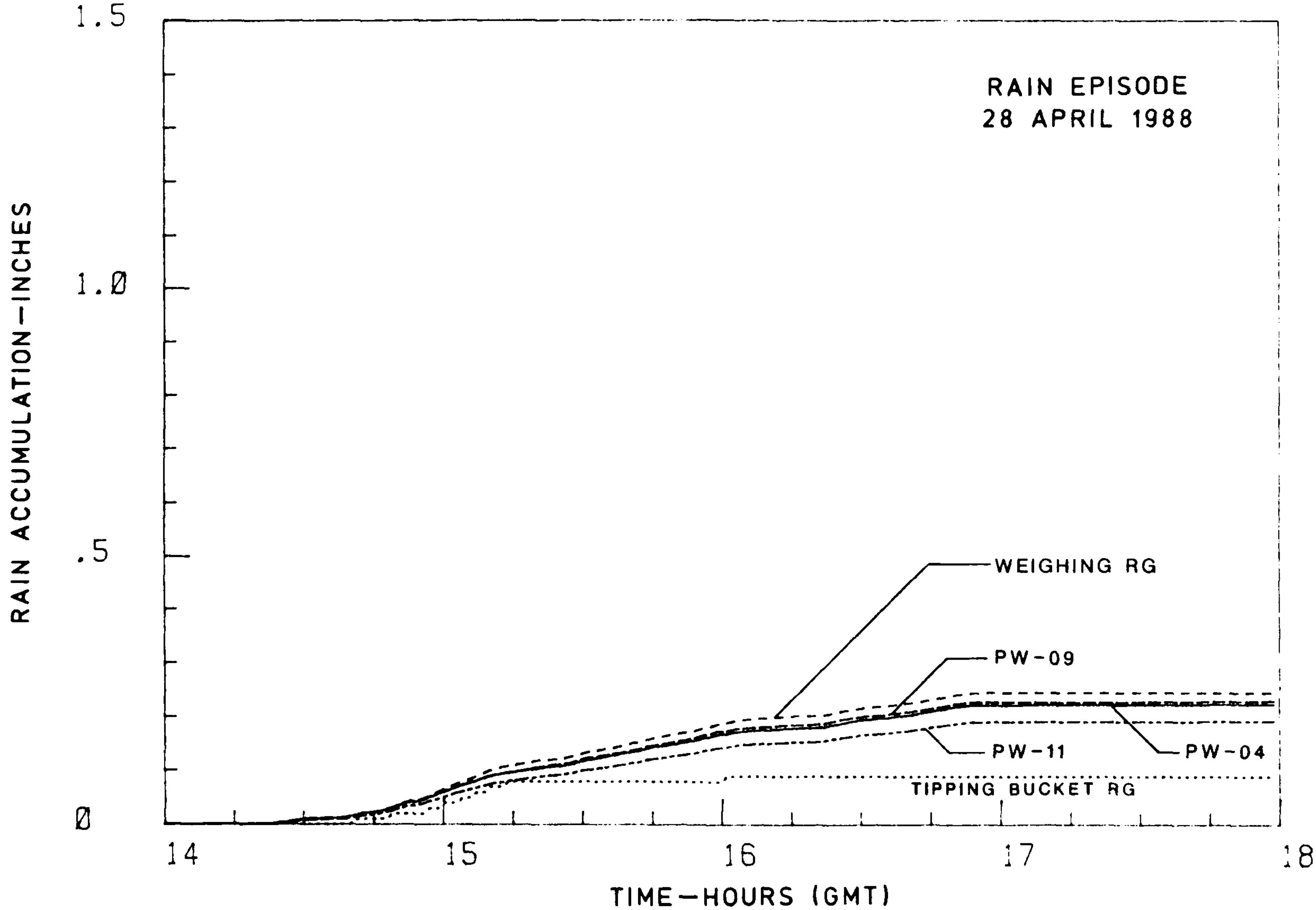

Figure 3.2 (a). Rain accumulation measurements by Sensors PW-04, PW-09, PW-11, a tipping bucket and the AFGL weighing rain gauge (22:00 - 24:00).

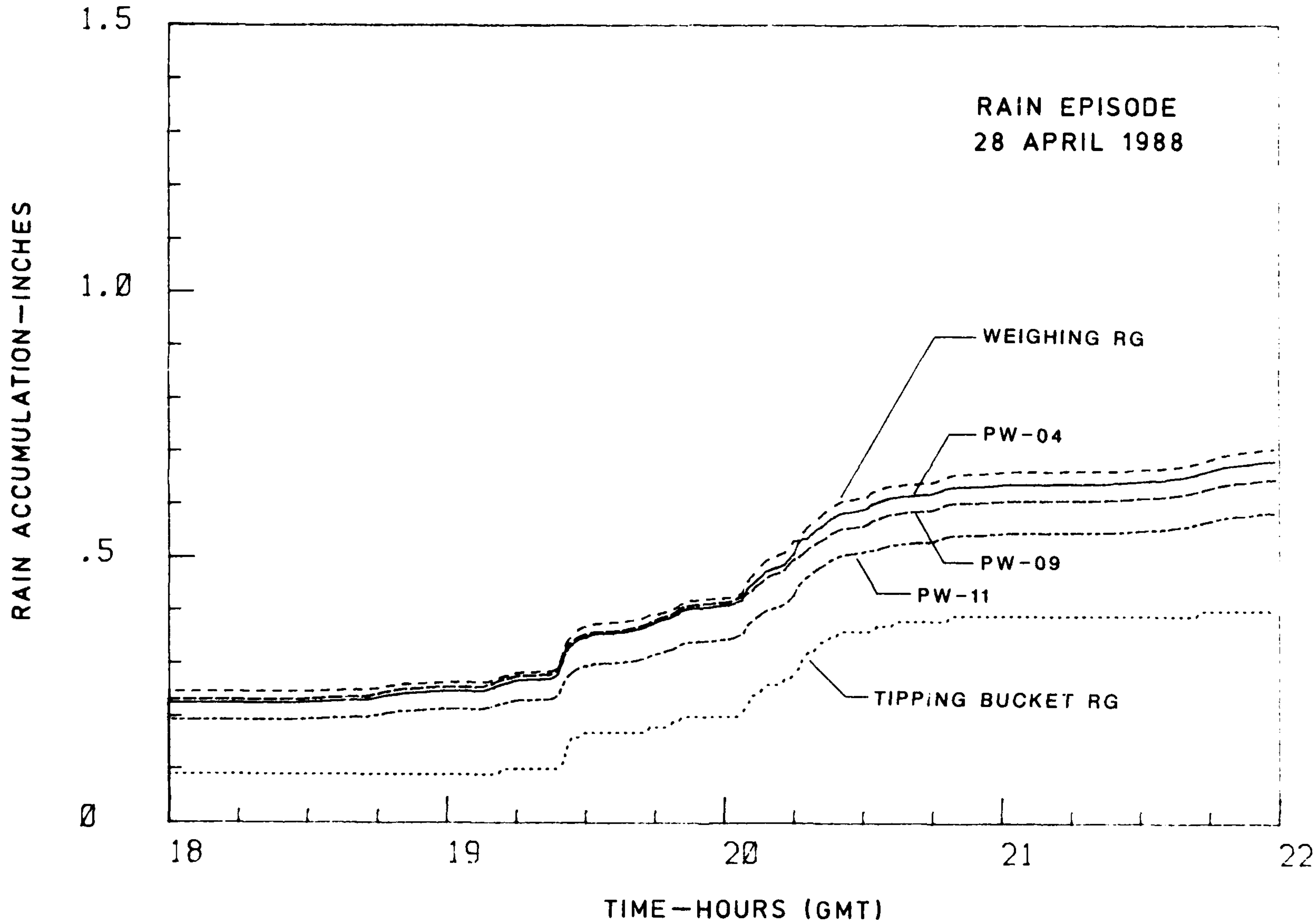

Figure 3.2 (b). Rain accumulation measurements by Sensors PW-04, PW-09, PW-11, a tipping bucket and the AFGL weighing rain gauge (18:00 - 22:00).

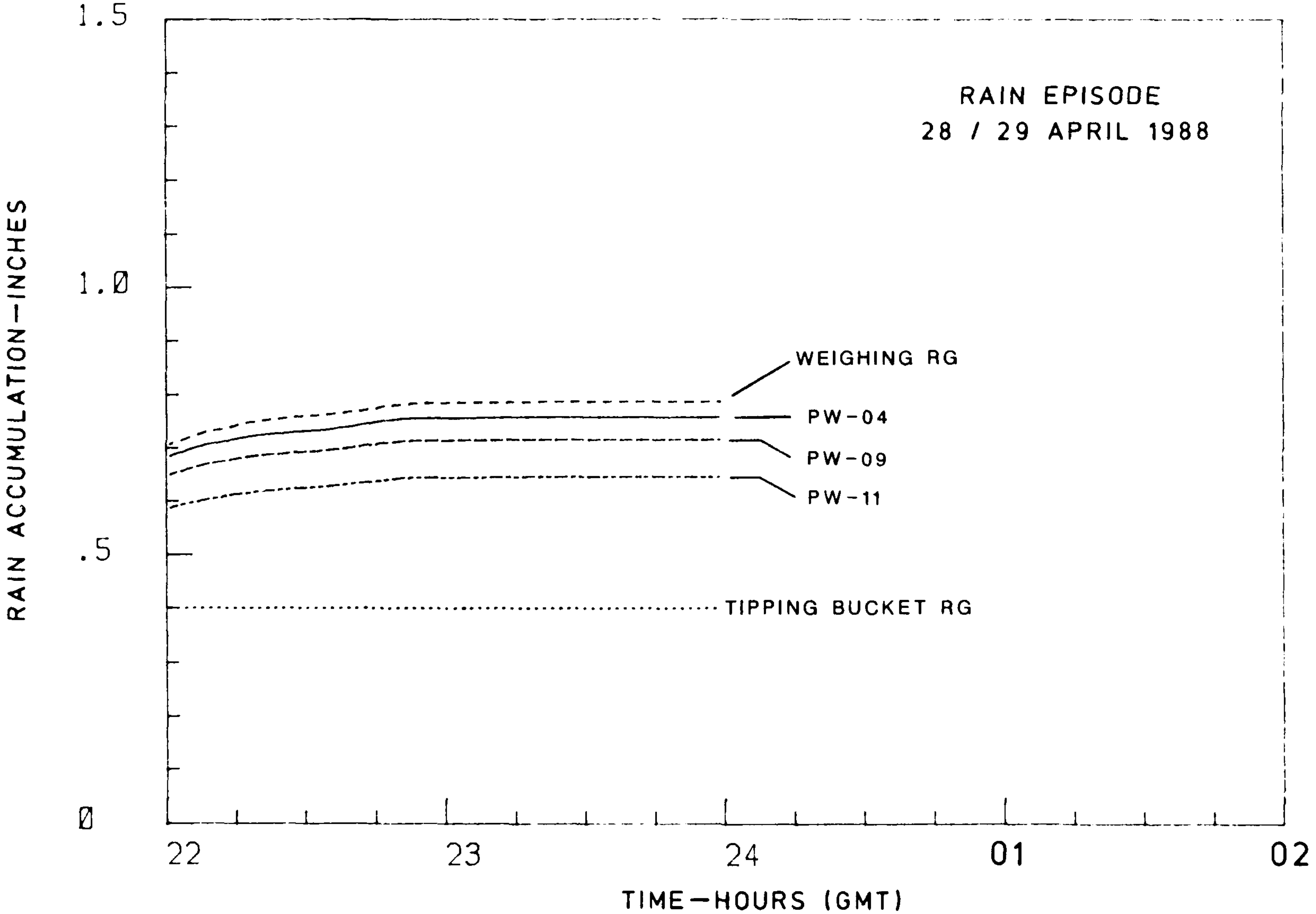

Figure 3.2 (c). Rain accumulation measurements by Sensors PW-04, PW-09, PW-11, a tipping bucket and the AFGL weighing rain gauge (14:00 - 18:00).

When the comparison of rain accumulation measurements between two sensors shows good agreement, then it is a reasonable assumption that the rainrate values which, when time-integrated, make up an accumulation measurement, must agree to an accuracy close to the accuracy determined for accumulation measurements. This assumption, however, is weighted in favor of the heavier rainrates. A rain gauge may not accurately measure very light rainfall or drizzle, or perhaps not even detect it, yet when accumulations are compared against a reference standard at the end of a rain episode, they could show agreement. This latter dilemma might be avoided by restricting the accumulation comparisons to portions of a rain episode where the rainrate is fairly constant and of the same intensity, if such data can be found.

To get an estimate of the rainrate measurement accuracy of the HSS Inc type of present weather sensors, the accumulation measurements of the PW-04 were compared with those of the weighing rain gauge for the winter 1987/1988 test period. Similar quantitative comparisons with the other HSS Inc type of present weather sensors were not made because of their failure to identify precipitation with the accuracy required by the ASOS performance specifications. Because the HSS Inc sensors apply a one-tenth density factor on all snow identifications to obtain the equivalent water content, any mis-identification of rain as snow will subject the accumulation values to error.

The criteria employed in the evaluation of the rainfall accumulation measurement accuracy of the PW-04 were as follows:

(1) The weighing rain gauge (WRG) was used as the reference standard.

(2) Only pure rain episodes were used in the comparison of measurements. Any portion of an episode with snow or mixed precipitation was excluded.

(3) Only rain episodes where the accumulation was equal to or greater than 0.10 inches in a four-hour time period were included.

The results of this evaluation are shown in Figure 3.3. Because of the striking change in the slope of the best-fit regression line that occurred midway through the test period, the comparison was separated into two time periods as shown in the figure.

During the first half of the test period there is a large systematic difference between the measurements of the two instruments. Only a minor systematic difference occurs during the second half of the test period.

No explanation has yet been found for the large systematic difference that occurred during the first half of the time period. All three sensors PW-04, PW-09 and PW-11 exhibited the same identical behavior. Wind speed and direction effects on the PW-04 sensor were examined as a possible explanation. It appears unlikely that these effects

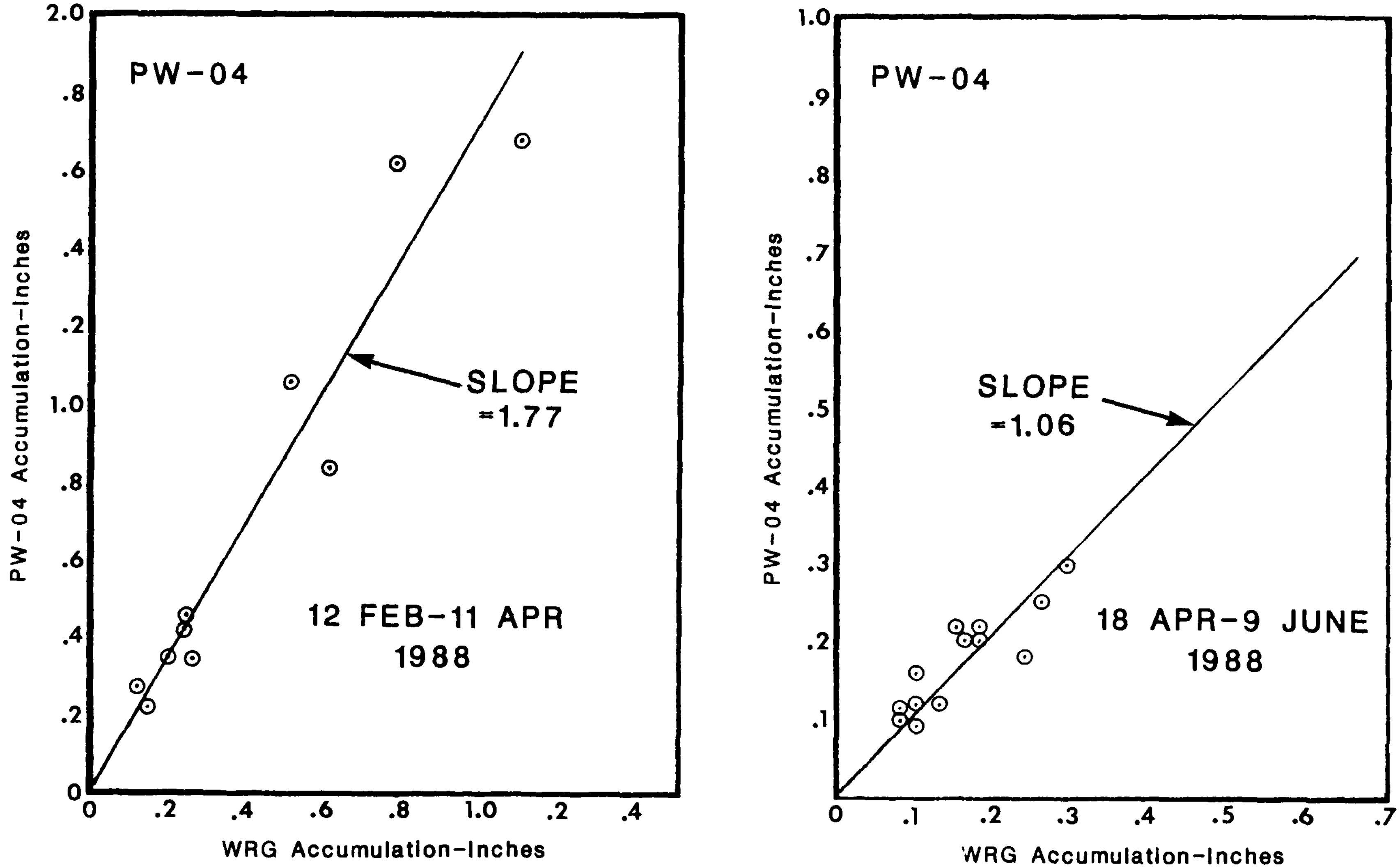

Figure : 3.3 Comparison of rain accumulation measurements over four hour time periods : PW-04 VS Weighing Rain Gauge.

were the cause. In both test periods, wind speeds in general ranged between 4 and 22 knots and the wind direction varied only between North to North North East.

If was not possible for HSS Inc to investigate any potential problems with the weighing rain gauge. Potential problems might arise from effects, heaters effects or a drift in the calibration.

The tipping bucket rain gauge, which might have provided an identification of which of the sensors had the systematic error, was malfunctioning through most of the entire test period and, therefore, of no assistance.

Because the systematic error could not be assigned definitively to either the PW-04 sensor or the weighing rain gauge, the statistical error of the PW-04 was determined by the deviations from the line of linear regression of the data points. The results are shown below.

TIME PERIOD	% RMS ERROR
12 Feb. - 11 April 1988	14.8
18 Apr. - 9 June 1988	3.0

The inability described above to establish true rain accumulations with a high degree of certainty, demonstrate the need to have at least three rain gauges, perhaps of varying types, as the reference standard during a performance test program.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This R&D program was intended to upgrade two AFGL present weather sensors through a series of hardware and software modifications to achieve two basic objectives: (1) to arrive at a sensor performance that would meet the ASOS/AWOS performance specifications, and (2) to provide additional sensor capabilities for Air Force present Weather Sensors beyond those required of present weather sensors as defined by the NWS-ASOS and FAA-AWOS specifications.

The ASOS and AWOS Present Weather Sensor specifications are concerned primarily with the detection and identification of precipitation and the measurement of its rate of fall. In the winter 1987/1988 test program, after hardware and software changes were made to the present weather sensors, the following capabilities were demonstrated with three newer model sensors that had the upgraded capabilities of the Air Force sensors.

(1) All three sensors meet the ASOS threshold detection requirements

(2) All three sensors meet the ASOS false alarm rate requirement

(3) One sensor (PW-04), the only sensor with a backscatter receiver channel, meets the ASOS precipitation identification requirements

(4) Left undetermined is whether the sensors meet the ASOS rainrate accuracy requirement because of uncertainites about the reference standard.

The program concentrated on achieving the first (primary) objective and did not succeed in achieving several of the secondary objectives which would have enhanced the sensor capabilities that are beyond those required of ASOS/AWOS sensors. Specific secondary upgrades that were, or were not, achieved are as follows:

Upgrades Achieved

1. Provide Transmissometer Equivalent EXCO's
2. Provide Graphic Video Display of Rainrate and Visual Range
3. Provide Semi-Automatic Calibration Checks

Upgrades Not Achieved

1. Identify Hail and Ice Pellets
2. Identify Mixed Precipitation
3. Resolve Differences in Density of Snow Particle Types
4. Distinguish between Fog and Smoke/Dust as an Obstruction to Vision

4.2 Recommendations

It has been demonstrated that an HSS Inc present weather sensor having a backscatter receiver channel can meet the ASOS precipitation detection, precipitation identification and false alarm rate requirements of the ASOS performance specifications. A question remains concerning its ability to meet the rainrate measurement accuracy requirement due to uncertainty about the reference standards employed.

The ability of HSS Inc present weather sensors to meet the ASOS detection and false alarm rate requirements is assured by the results achieved with several sensors in the present program. Further testing with a number of sensors having backscatter receiver channels needs to be performed to insure that the ASOS precipitation identification requirements can be achieved by more than just the prototype sensor.

The HSS Inc Present Weather Sensors already provide more functional capability than is required of ASOS/AWOS sensors. They can measure visual range and determine whether for is accompanying any form of precipitation. They have an on-board temperature sensor with provision for an on-board relative humidity sensor. Alternatively, they can communicate with other systems to acquire temperature or relative humidity measurements for use in on-board identification algorithms. As yet, temperature has never been used for purposes of identifying precipitation because it would interfere with the improvement of identification algorithms and also interface with the testing of sensor capabilities. However, there is indication that ASOS and AWOS systems will someday permit the utilization of temperature as part of the precipitation identification process.

The addition of the backscatter receiver channel opens up the possibility of achieving some of the secondary goals which were not achieved under the present program: e.g., (1) identification of hail and ice pellets, (2) identifying mixed precipitation, (3) resolving differences in densities of snow particle types (and thus assuring accurate snow accumulation measurements) and (4) distinguishing between fog and smoke/dust.

Also, further sensor tests of the rainrate and rain accumulation accuracies are indicated. But, such tests should employ at least three independent reference rain gauges and assume that two out of the three are in agreement to within the accuracy required of the ASOS sensors in order to have a reliable reference standard by which to judge the accuracy of the present weather sensors.

The subject of snowfall accumulation accuracies was not addressed in this program. Now that highly reliable precipitation identifications are achievable any future test program should address this subject.

A concept called sensor fusion is evolving in the military application of all forms of sensors. It refers to the development of multifunction sensors that share housings, optics, detectors, signal processors and displays to achieve measurable improvement in capability, affordability and reliability.

If all secondary goals can be added to the present weather sensor capabilities, then a significant number of difficult meteorological measurements could be made by the one automated sensor.

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APPENDIX A

MEASUREMENT PRINCIPLES
OF THE
HSS INC PRESENT WEATHER SENSORS

NOTE: This Appendix refers to the Model PW-403 Present Weather Sensor. The measurement principles of other models of HSS Inc present weather sensors are similar in all respects.

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A-0 MEASUREMENT PRINCIPLES

A-1 Visibility Measurements

The PW-403 has all the features of a forward-scatter visibility sensor; i.e., it belongs to the class of nephelometers which measure the amount of light scattered at angles less than 90 degrees by small particulates suspended in, or large particles passing through, its sample volume. In the case of the PW-403, the sample volume is defined by the intersection of the transmitted beam of light and the ray-cone which defines the field of view of the receiver system as shown in Figure A-1.

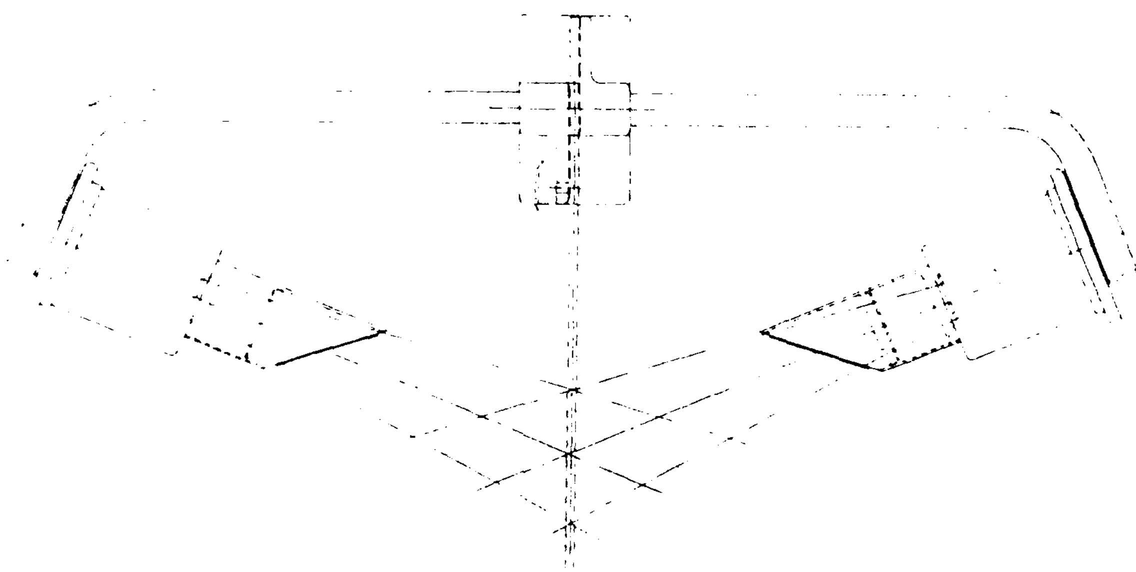


Figure A-1. Top view of PW-403 Sensor Head.

Suspended particles such as fog, haze and smoke aerosols and precipitating particles such as rain, snow, ice pellets, drizzle and mist account for essentially all of the atmospheric extinction of visible and near-visible optical radiations for horizontal visual ranges up to approximately 100 kilometers. Beyond that range scattering by the molecular constituents of the atmosphere begin to play a role. In the visible and near visible spectral regions the dominant aerosol attenuation process is Mie-scattering. Aerosol absorption plays a negligible role in most natural environments, thus the atmosphere scattering coefficient and extinction coefficient are synonymous.

Visual Range Determination

Nearly all instrumental methods of determining visual range start with a quantitative measurement of the atmospheric extinction coefficient β. Because β is measured in the vicinity of the instrument an assumption must be made that the prevailing environmental conditions are uniform over the scale of visual ranges of interest. The extinction coefficient is converted to visual range by application of: (1) Koschmieder's Law (for daytime visual range), Allard's Law (for nighttime visual range), or (3) variations on Koschmieder and Allard's Laws.

When an observer looks at a distant target the light from the target that reaches the observer is diminished by absorption and scattering (the two components of extinction). In addition to the light which originates at the target and ultimately reaches the observer, extraneous light scattered into the line-of-sight by the intervening atmosphere is also seen by the observer. It is this air light which we recognize as haze or fog.

The effect of extinction and added air light on the perceived brightness of visual targets is shown graphically in Figure A-2. From this illustration we note that the apparent contrast between object and horizon sky decreases with increasing distance from the target. This is true for both bright and dark objects.

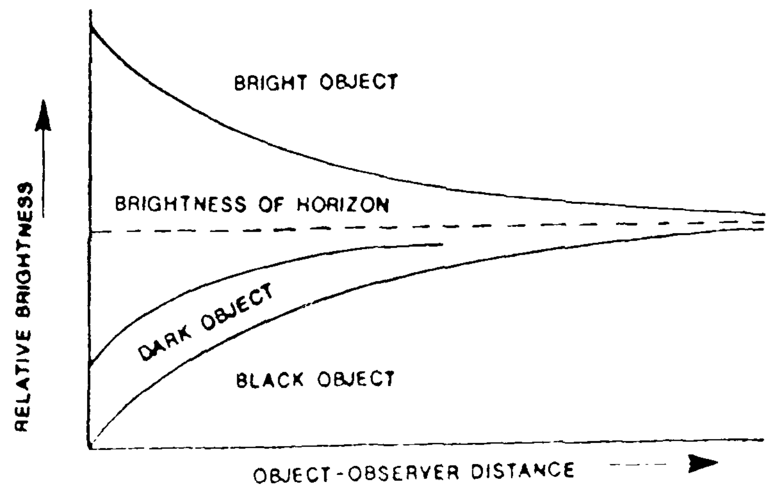


Figure A-2. Effects of Atmosphere on the Apparent Brightness of Target Objects.

Daytime Visual Range

The original formula for calculating daytime visual range V_R which was formulated by Koschmieder in 1924 is

$$V_R = \frac{3.912}{\beta}$$

where δ is the atmospheric extinction coefficient. Subsequent investigations concluded that Koschmieder used too optimistic a value (0.02) for the liminal contrast threshold value of the human eye. A liminal value of 0.05 is believed to be more realistic. For the latter contrast threshold Koschmieder's Law is modified to become

$$V_R = \frac{3.00}{\delta}$$

This simple law accounts for both the extinction of light by the atmosphere and the addition of air light by the same atmosphere --- for a black target viewed against the horizon sky. Thus, the strict definition of daytime visual range implies the limiting distance at which a black target can be discerned against the horizon sky.

Nighttime Visual Range

Nighttime visual range refers to the distance at which an observer can see lights through the atmosphere at night. The formula for the distance at which lights of intensity I can be seen at night was given by Allard in 1876. Allard's Law is expressed as:

$$E_t = I\, e^{-\delta V}/V^2$$

where E_t is the observer's illuminance threshold and δ is the atmospheric extinction coefficient. In addition to the extinction of light by the atmosphere, this formula accounts for the decrease of light from the point sources of light as the inverse square of the distance.

This formula for calculating nighttime visual range has a significant mathematical difference from the formula derived from Koschmieder's law. Where the latter has a single algebraic relation between visibility and extinction coefficient, the former has a transcendental relation between the two quantities. Thus, the solution can only be found by an iterative numerical procedure or from a prepared table of values.

Sensor Calibration

The calibration of the prototype PW-403 was carried out at the Weather Test Facility (WTF) of the Air Force Geophysics Laboratory which is located at the Otis Air National Guard Base (ANGB) on Cape Cod, Massachusetts. The calibration was made by comparison of measurements with those of standard FAA approved transmissometers. Comparisons were made over an extremely wide range of fog and haze situations.

The calibration of each PW-403 Present Weather Sensor is traceable to the measurements made with the prototype instrument at the AFGL Weather Facility. This "primary" calibration is transferred to other instruments of the same type using a "primary reference standard" whose "equivalent extinction coefficient" was established at the

time of the primary calibration. A secondary reference standard similar in construction to the primary standard is furnished with each instrument so that the sensor calibration can be periodically checked. The secondary reference standard has received its value of equivalent extinction coefficient by a comparison with the primary reference standard. The calibration constant for the secondary reference standard.

Measurement Range

The visibility measurement range is a fixed range that is set at the factory. It cannot be changed by the operator in the field. If a change of coverage is required, the sensor must be returned to the manufacturer.

A-2 Precipitation Measurements

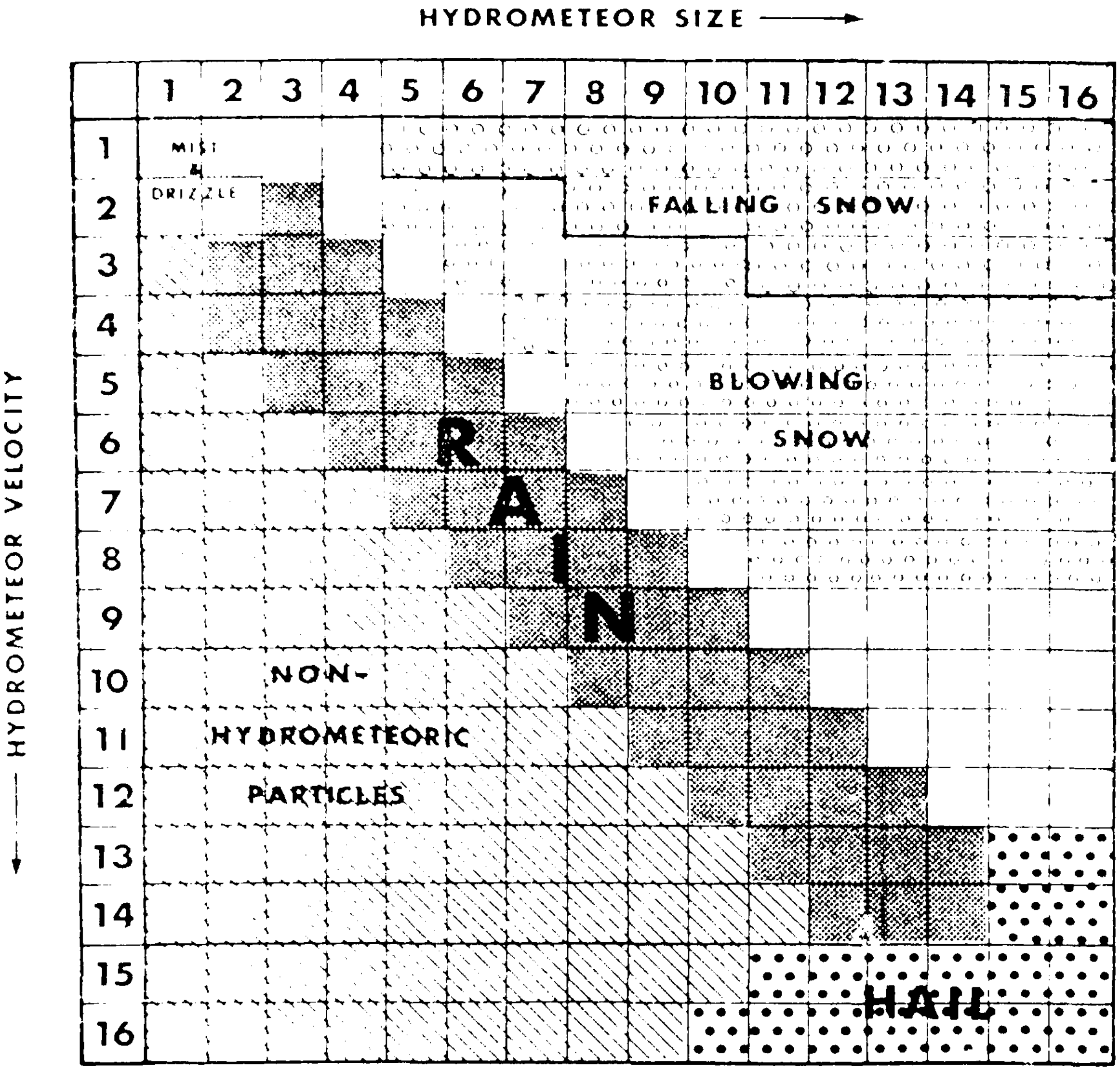
Outline of Principles

The PW-403 determines the type and quantity of precipitation in addition to the visibility. It measures the amplitude and duration of the light pulse caused by each precipitation particle falling through the sample volume to determine the particle size and velocity. The size and velocity information is stored in a data matrix by the microcomputer. The particle size/velocity data is collected and stored for a time interval (the measurement time period, usually one minute) adequate to provide a statistically significant and representative sample of particle sizes and velocities. The size and velocity distributions of particles in the matrix are used to determine the type of precipitation as shown in Figure 2-3. Small numbers of particles with distributions not indicative of rain or snow are considered not to be precipitation and are rejected by false alarm algorithms.

Once precipitation occurrence has been determined, the particle size/velocity distributions are used to identify the type of precipitation and to measure its intensity. To measure the intensity, the number of particles in each size bin of the matrix are summed, then multiplied by the equivalent volume of water and a calibration constant. If the precipitation is identified as snow, a density factor is applied to determine the equivalent water content.

Precipitation Recognition Matrix

A size/velocity matrix is a very convenient presentation for identifying various forms of precipitation. For this reason we have termed such a matrix the "Precipitation



MATRIX SCALES

COLUMNS

NO.	[illegible]
1	[illegible]
2	[illegible]
3	[illegible]
4	[illegible]
5	[illegible]
6	[illegible]
7	[illegible]
8	[illegible]
9	[illegible]
10	[illegible]
11	[illegible]
12	[illegible]
13	[illegible]
14	[illegible]
15	[illegible]
16	[illegible]

ROWS

NO.	[illegible]
1	[illegible]
2	[illegible]
3	[illegible]
4	[illegible]
5	[illegible]
6	[illegible]
7	[illegible]
8	[illegible]
9	[illegible]
10	[illegible]
11	[illegible]
12	[illegible]
13	[illegible]
14	[illegible]
15	[illegible]
16	[illegible]

FIGURE : \-..GENERAL SIZE/VELOCITY CHARACTERISTICS OF VARIOUS TYPES OF PRECIPITATION DISPLAYED ON THE PRECIPITATION RECOGNITION MATRIX.

Recognition Matrix". Types of precipitation are identified from their "Signature" in the Precipitation Recognition Matrix. The "Signature" is the particle size velocity distribution that is characteristic of each type of precipitation phenomena.

An example of a precipitation recognition matrix is shown in Figure A-3. This figure portrays a 16 x 16 matrix array of particle sizes and velocities. Sizes are arranged in columns and velocities in rows.

The Marshall-Palmer model for raindrop size-distribution and the Gunn-Kinzer measured velocities for raindrops in stagnant air were used to establish the matrix scales. If rainfall behaved in the exact manner of the Marshall-Palmer and Gunn-Kinzer models all raindrop measurements would fall in the data bins along the diagonal of the Precipitation Recognition Matrix. In practice, several factors tend to disperse the size/velocity relationship from the idealized characterizations: (1) the Marshall-Palmer size distribution for raindrops is only a best-fit approximation, (2) winds and wind gusts can perturb the velocity/size relationship, (3) the shape of the sample volume can significantly influence the velocity/size characteristics of particles (i.e., particles falling through a portion of the sample volume other than the center, or falling in other than a vertical direction because of wind, will exhibit slightly different velocity/size characteristics depending upon the shape of the sample volume and the direction of the wind).

For the foregoing reasons, one expects raindrop counts to show up in some off-diagonal bins of the Precipitation Recognition Matrix as shown in the schematic illustration given in Figure A-3. Indeed, this conjecture is substantiated in practice. Figure A-3 is, however, a realistic portrayal of the use of the Precipitation Matrix to identify different kinds of precipitation. The locations of various forms of precipitation which are schematically illustrated in the matrix are also borne out in practice.

Signal Processing

A functional block diagram of the PW-403 is shown in Figure A-4. Those components of the PW-403 housed in the sensor head are shown above the dashed line. Those components housed in the control unit are shown below the dashed line.

When a particle of precipitation passes through the sample volume, light from the LED source which is housed in the transmitter section of the sensor head is scattered into the receiver section where it is sensed by the photo detector. Because the LED source is modulated at a 2 kHz frequency, the detector and amplifier chain generates an AC signal whose amplitude is proportionally to the size of the particle and whose duration is inversely proportional to its velocity.

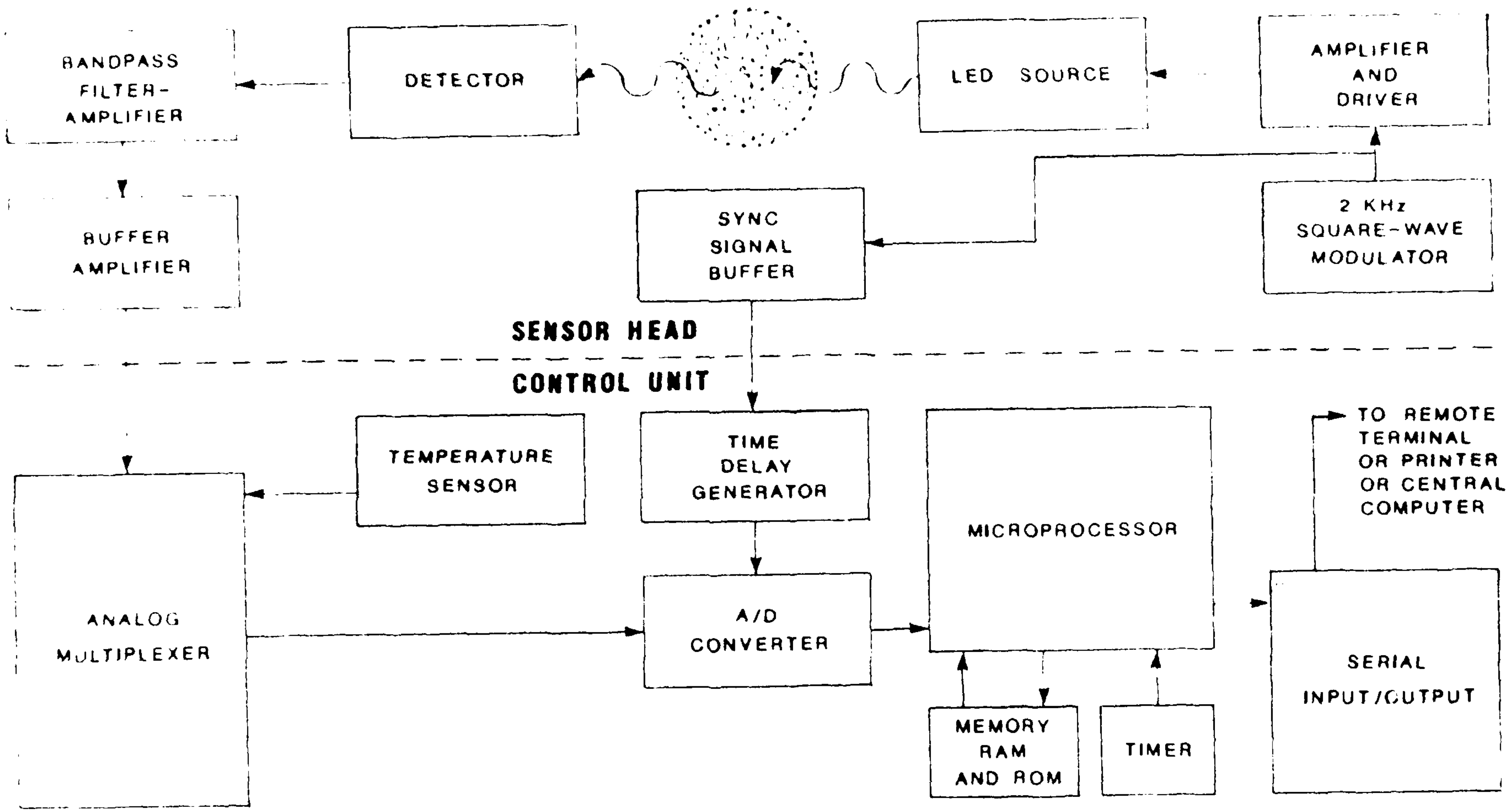


Figure A-4. Block Diagram of the PW-403.

The AC signal is sent to the microprocessor located in the control unit via an analog multiplexer and A/D converter. The signal from a dedicated temperature sensor is sent to the microprocessor along the same route. The microprocessor requires both RAM and ROM storage and an electronic timer. Data is collected, processed and stored by the microprocessor during each sample time period.

A 12-bit A/D converter is used to digitize signals from the sensor head and the temperature sensor. The multiplexer is directed by the microprocessor to continuously monitor the AC signal except for a periodic momentary interruption when the temperature sensor signal is to be sampled. Digitization of the AC signal occurs by a sync-signal derived from the source modulator. The AC signal is digitally sampled only at the time of peak positive and negative values of the signal. The negative peak values are inverted, causing the signal to be digitally rectified.

The rectified AC signal is treated by three digital filters as shown in Figure A-5. These three filters are identified as: (1) the large/fast particle filter, (2) the small/slow particle filter, and (3) the fog-tracking filter. Adaptive thresholds are used to discriminate between signal pulses due to precipitation and spikes due to noise generated within the detection process. A peak-detect routine is used to find the maximum signal value. The time spent by a particle traversing the sample volume is measured by counting the number of data samples representing the rectified signal pulse.

If a precipitation particle is detected by both Adaptive Threshold A and Adaptive Threshold B, then the peak-signal-value and time-in-sample volume measured by Chain A of the software routine are adopted. Peak-signal-values and time-in-sample volumes measured by Chain B of the software routine are adopted only if Adaptive Threshold B is crossed and Adaptive Threshold A is not crossed.

The output of the digital synchronous rectifier is also sent to a very narrow band filter whose purpose is to provide a filtered signal representing the atmospheric coefficient. An identical filter with an added control input provides a signal representing the atmospheric coefficient with the effects of particles removed. To achieve this result, the filter is directed by the OR-Gate, indicated in Figure A-5, to ignore the rectified AC signal whenever either of the adaptive thresholds has detected a precipitation particle.

Particle Classification

The Particle Classification Process indicated in Figure A-6 is the software routine that sorts particles of various sizes and velocities into bins as represented in the

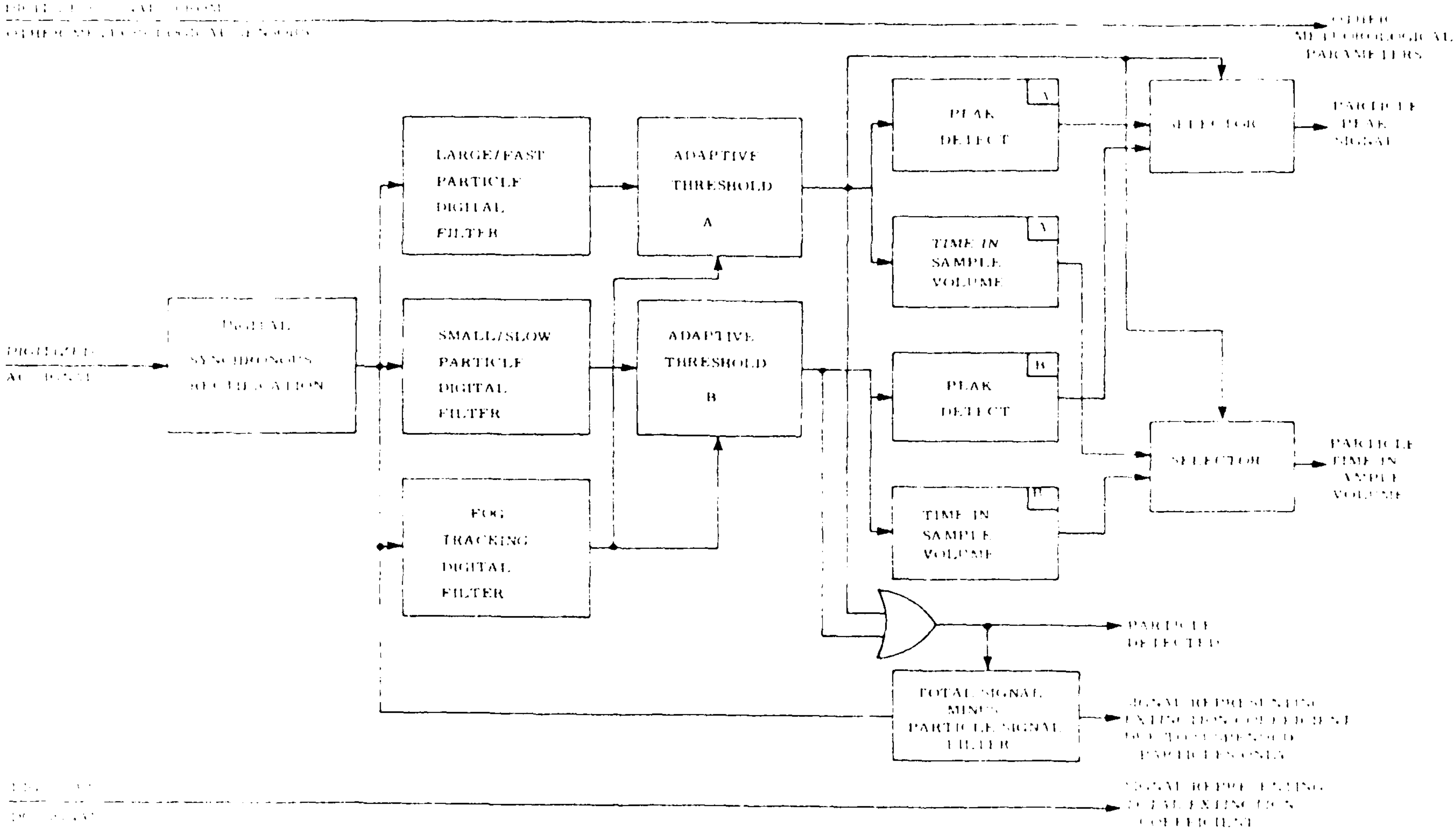


FIGURE : A-5. BLOCK DIAGRAM OF THE MICROPROCESSOR COMPUTER PROCESS: PART ONE

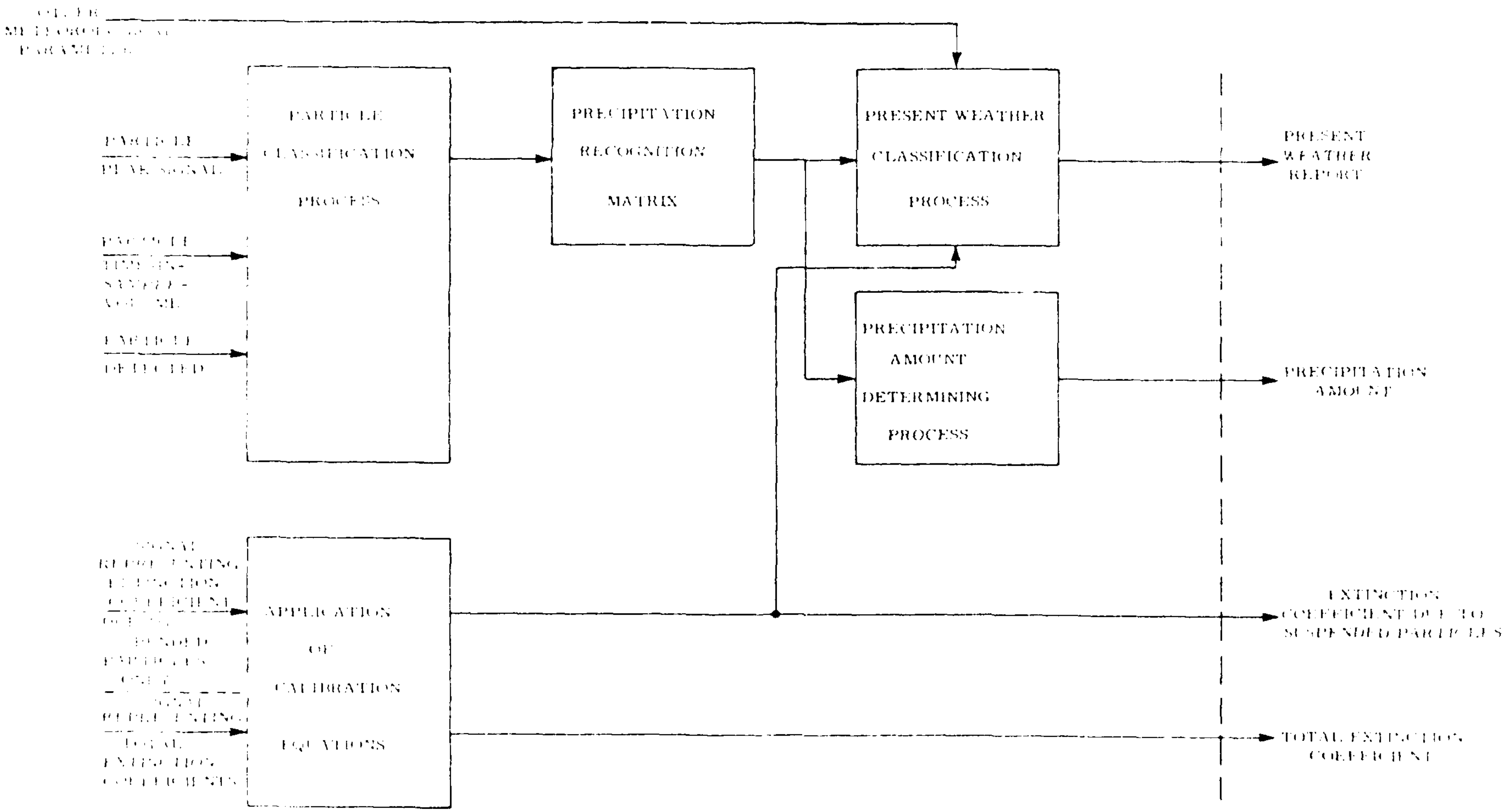


FIGURE : A-6. BLOCK DIAGRAM OF THE MICROPROCESSOR COMPUTER PROCESS : PART TWO

precipitation recognition matrix. The peak values are used to place particles in one of twenty-one amplitude categories representing twenty-one particle size groups. These groups include the smallest detectable particle to the largest particle that does not saturate the detector electronics. Similarly, time-in-sample volume values are used to categorize particle velocities in one of twenty-one velocity groups.

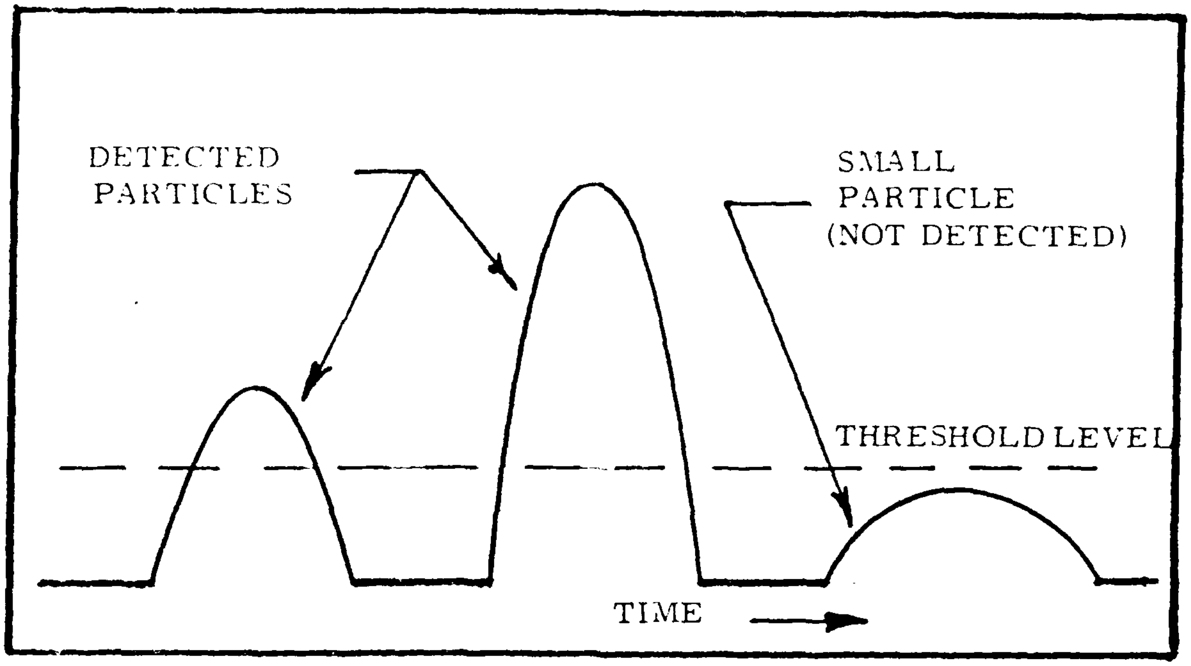
Velocity is determined from the time-in-sample volume as shown in Figure A-7 using the vertical dimension of the sample volume as the distance traveled in that time.

Once the size and velocity of a particle are established, the matrix bin appropriate to those values is identified and the particle number in that bin is incremented by one count.

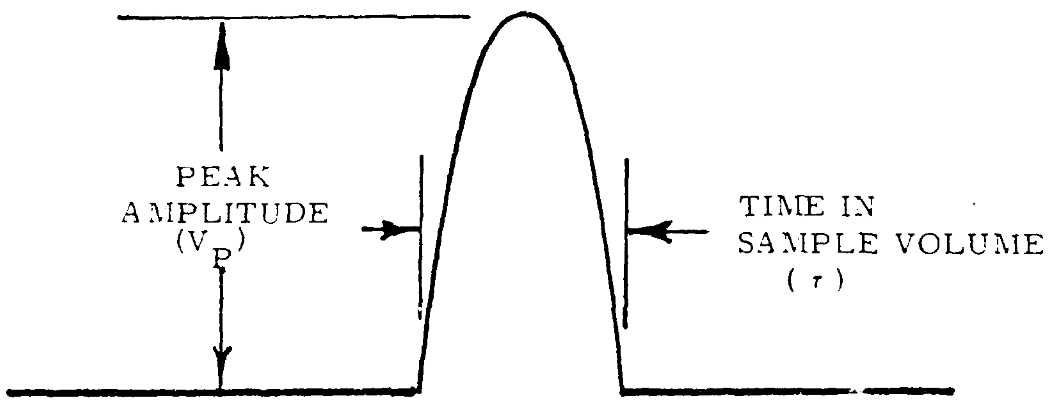
Rainfall: The rainfall intensity is determined by first calculating the water content (volume) of each detected drop and summing the volume of all drops to get the total amount of water passing through the sample volume. The final step in the process requires a knowledge of the area through which the drops fell and the application of an empirically established calibration constant. The intensity of rainfall is calculated on a minute-to-minute basis.

Snowfall can also be measured by the PW-403. The method utilizes an empirically established density factor applicable in general to all forms of snow (but not ice pellets). The value of that empirical density factor for snow has been found to be 0.1. Thus, if a given form of precipitation has been established as snow the equivalent water content is found by calculating the amount of water that has passed through the sample volume assuming hypothetical spherical particles of the dimensions represented by each column of the precipitation recognition matrix then multiplying the result by the 0.1 density factor to find the equivalent water content.

PARTICLE DETECTION



SIZE AND VELOCITY MEASUREMENT



$V_P = KR^2$

K = Calibration Constant
R = Raindrop Radius

$S = L/\tau$

S = Velocity of Particle
L = Pathlength in Sample Volume

FIGURE : A-7. TECHNIQUES USED IN PARTICLE DETECTION AND PARTICLE SIZE AND VELOCITY MEASUREMENTS.

APPENDIX B

OPERATING CHARACTERISTICS
OF THE
MODEL PW-402A PRESENT WEATHER SENSOR

TABLE OF CONTENTS

OPERATING STATE CONFIGURATION

The operating state of the PW-402A-121 is determined by the current binary value of the operating state word (changed by the "OS" command) and the wiring to the Processor Board connector P6 pin 2 (P6-2). The operating state word is stored in non-volatile memory and the PW-402A-121 will power up in its last set state, assuming that Processor Board connector P6 has not been changed. For PW-402A-121 normal operation P6-2 must be kept open. P6-2 selects a special RF Modem/Radio communications protocol that is not implemented for the PW-402A-121.

The logic for determining the operating state has this restriction:

If OS Word Bit 3 is "1" (Intermittent mode selected), OS Word Bit 2 is disabled. Data calculation as part of response to "D?" or "A" command is inhibited.

Example Configurations:

1. PW-402A-121 operated continuously
   Weather identification calculated every minute
   Expanded data messages
   Calibration commands disabled

   Send commands: TM60
   OS0

2. PW-402A-121 operated continuously
   Weather identification calculated and messages sent only when command "D?" or command "A" sent (polled mode)
   Expanded data messages
   Calibration commands disabled

   Send commands: OS10

OPERATING STATE CONFIGURATION (continued)

Example configurations (continued)

3. PW-402A-121 operated continuously

   Weather identification calculated and messages sent only when command "D?" or command "A" sent (polled mode)

   Expanded data messages

   Calibration commands enabled

   Send commands: OS10010

SYSTEM IDIOSYNCRASIES

The PW-402A-121 was designed to be configured for any possible operating scenario. The system should allow complete operator control over instrument operation while preventing instrument damage or incorrect instrument performance. These design goals are sometimes in conflict and result in system charactistics that can cause user confusion.

System Reset

There are two levels of system reset, complete and functional. Complete reset includes initialization of all instrument programmable hardware functions including the communications protocol followed by a functional reset. Functional reset includes the following:

1. Nonvolatile memory is read and parameter values are set execpt for the communications protocol in use. A change in communications protocol is made with a complete reset.
2. All timing is initialized, there is a 10 second stabilization period followed by a measurement period.
3. All data is initialized.

Complete reset is caused by the following:

1. System power is applied.
2. Changes are made to the connections to the Processor Board connector, P6.

Functional reset is caused by the following:

1. Receipt of an "RST" command.
2. Receipt of an "OS" command.
3. Completion of a calibration sequence in response to a "CE" or "CT" command.

Programmable parameters

Many parameter values are can be changed by commands and are stored in the nonvolatile memory. Examples of these parameters are:

Measurement period set by the "TM" command

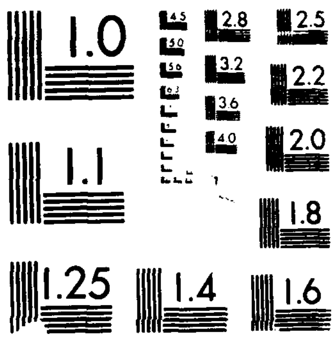
Instrument identification number set by the "ID" command

When a parameter value is changed by command, the new value will not be incorporated in instrument operation until a functional reset occurs.

AD-A207 669 A PROGRAM TO IMPROVE PERFORMANCE OF AFGL (AIR FORCE GEOPHYSICAL LABORATOR (U) HSS INC BEDFORD MA D F HANSEN ET AL 01 AUG 88 HSS-B-169 AFGL-TR-88-0329 2/2

UNCLASSIFIED F19628-86-C-0061 F/G 4/2 NL

END
FILMED
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

CHECK SUM USAGE

The PW-402A-121 communications protocol uses a check sum if the Processor Board J6 pin 3 is shorted to pin 10. All messages from the instrument will include a check sum value. Input commands that do not have a valid check sum value will not be executed and the response will be:

BAD CK SUM<ck sum><end chars>

The check sum is positioned after the message and before the end characters. The check sum value is between 0 and 127, and is the sum modulo 128 (the remainder after the sum is divided by 128) of all the ASCII values of the characters in the message except the end characters. The check sum value is replaced by its bit wise complement if it happens to be either ASCII 8 (backspace), ASCII 10 (linefeed), ASCII 13 (carriage return), or ASCII 33 (exclamation point "!").

The calculation is as follows:

$$\underbrace{c_1 \ldots c_m}_{\text{message}}\text{<ck sum><end chars>}$$

$$\text{<ck sum>} = \left(\sum_{n=1}^{m} c_n \right) \text{ MOD } 128$$

IF <ck sum> = 8 THEN <ck sum> = 119

IF <ck sum> = 10 THEN <ck sum> = 117

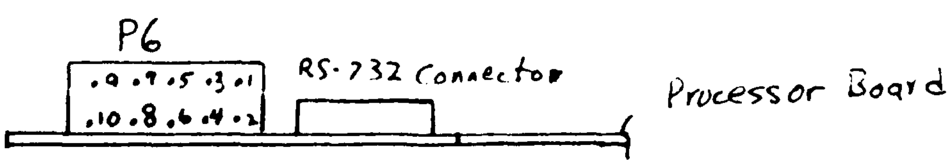
IF <ck sum> = 13 THEN <ck sum> = 114

IF <ck sum> = 33 THEN <ck sum> = 94

PROCESSOR BOARD CONNECTOR P6 POSITIONS

Shorted means connected to P6 pin 10. Connections can be made in daisy chain fashion using wire wrap methods.

P6 Pin	Setting	Meaning
2	Open	Must be open
3	Open	No check sum for communications messages
	Shorted	Each command message to the PW-402A-121 must include a one byte check sum and each response from the PW-402A-121 will include a check sum byte
4		Not used
5,6	5 Open 6 Open	Preset Communications parameters selected: Baud rate .... 1200 Bits per word .... 8 Transmit parity ...... None Receive parity .... None Stop bits 1
	5 Open 6 Shorted	Programmable communications parameter set 1 selected: Baud rate .... 300 Bits per word .... 7 Transmit parity .... Odd Receive parity .... Odd Stop bits 2
	5 Shorted 6 Open	Programmable communications parameter set 2 selected Baud rate .... 600 Bits per word .... 7 Transmit parity .... Odd Receive parity .... Odd Stop bits 2
	5 Shorted 6 Shorted	Programmable communications parameter set 3 selected Baud rate .... 1200 Bits per word .... 7 Transmit parity .... Odd Receive parity .... Odd Stop bits 2



PROCESSOR BOARD CONNECTOR P6 POSITIONS (continued)

P6 Pin	Setting	Meaning
7,8	7 Open 8 Open	End characters for each communications line are <CR><LF>
	7 Open 8 Shorted	End character for each communications line is <CR>
	7 Shorted 8 Open	End character for each communications line is <LF>
	7 Shorted 8 Shorted	End character for each communications line is <CR>

NOTE:
If end character <LF> is not selected (P6-8 shorted), end character <CR> is selected irrespective of P6-7 state.

OPERATING STATE MESSAGE BINARY BIT MEANINGS

The numeric value included with the operating state command determines the operating configuration of the PW-402A-121. This value is entered as a binary number (1's and 0's). Leading 0's in the value need not be entered. The value is stored in non-volatile memory and the operating configuration when power is applied is that set by the last entered operating stated command. The command has the following syntax:

```
OSbbbbbbbb<end chars>
 |||||||
 |||||||Bit 1: Must be 0
 ||||||
 ||||||Bit 2: 1 = Calculate values and determine data message
 |||||            in response to "D?" or "A" command,
 |||||            ignoring measurement interval timing
 |||||        0 = Values calculated and data message
 |||||            determined after each measurement interval
 |||||
 |||||Bit 3: 1 = Intermittent mode of operation
 ||||         0 = Continuous mode of operation
 ||||
 ||||Bit 4: Not used
 |||
 |||Bit 5: 1 = Calibration commands enabled ("CE" and "CT"
 ||            commands)
 ||        0 = Calibration commands disabled
 ||
 ||Bit 6: 1 = Compressed data message mode
 |        0 = Expanded data message mode
 |
 |Bit 7: Not used
 |
Bit 8: Not used
```

EXAMPLES

OS0<end chars>
Expanded data message mode
Calibration commands disabled
Continuous mode of operation
Values calculated and data message determined after each measurement interval

OS10010<end chars>
Expanded data message mode
Calibration commands enabled
Continuous mode of operation
Values calculated and data message determined after each "D?" or "A" command

COMMAND AND RESPONSE MESSAGES

Command Messages

Command	Quantitative Response	Meaning
A<end chars>	See LEDWI Message	Send LEDWI message
A?<end chars>	See Precipitation Accumulation Message	Send accumulated precipitation and time of accumulation
AC<end chars>	None	Clear accumulated precipitation and time
BT?<end chars>	sxxx.xx	Send present value of Total EXCO (Beta)
BL?<end chars>	sxxx.xx	Send present value of EXCO (Beta) less precipitation particle component
C?<end chars>	See Calibration Parameters Message	Send calibration parameters message
CE<end chars>	See EXCO Calibration	Perform EXCO calibration (Cal bit in Operational State must be set)
CT<end chars>	See Temperature Calibration	Perform temperature calibration (Cal bit in Operational State must be set)
D?<end chars>	See Operational Message	Send latest operational message
Dn?<end chars>	Operational messages with "O" prefix	Send accumulated operational messages, starting with the latest for n messages (1 to 10)
IDxx<end chars>	None	Set instrument identification number (0 to 99)

NOTE:
<end chars> are set by Connector P6 on Processor Board. Refer to table of Processor Board Connector P6 positions.

COMMAND AND RESPONSE MESSAGES (continued)

Command Messages (continued)

Command	Quantitative Response	Meaning
M?<end chars>	See Matrix Response	Send Precipitation Matrix accumulated over last 5 measurement periods (in intermittent mode matrix is for last measurement period)
OSb[b...]<end chars>	None	Set Operational State (See Operational State Bits
P?<end chars>	See Parameter Message	Send parameter values
PCn?<end chars>	See RS232C Comm Parameters	Send communications parameter set n (1 to 3)
R?<end chars>	See Remote Maintenance Message	Send remote maintenance message
RST<end chars>	None	Restart instrument
T?<end chars>	See Instrument Times Message	Send instrument times message
TAxxxx<end chars>	None	Set sample period for auxiliary measurements (seconds)
TDxxxx<end chars>	None	Set delay before sending each line of a message (milliseconds)
TIxxxx<end chars>	None	Set operating period for intermittent mode (seconds)
TMxxxx<end chars>	None	Set measurement period (seconds)

NOTE:
<end chars> are set by Connector P6 on Processor Board. Refer to table of Processor Board Connector P6 positions.

COMMAND AND RESPONSE MESSAGES (continued)

Standard Response Messages

Response	Meaning
TIMEOUT<end chars>	Command was sent with more than 10 seconds between characters; start over
COMM ERR<end chars>	An error was detected in a character in the command; start over
TOO LONG<end chars>	Command message was longer than 24 characters including end characters; start over
OK<end chars>	Command with no quantitative response was understood and executed
BAD CMD<end chars>	Command was not among those understood by instrument
BAD CK SUM<end chars>	Command check sum character does not match the calculated check sum for the command (occurs only when the check sum mode is active)

LEDWI MESSAGE FORMAT

Sent in response to command "A"

```
cs00c<end chars>
|||||
||||O = All RMM values OK
||||X = Some RMM values indicate fault
||||
|||Reserved
|||
||Reserved
||
X  = Weather Identification unknown, time since instrument
     reset insufficient to make determination
N  = No precipitation
L- = Light drizzle
L  = Moderate drizzle
R- = Light rain
R  = Moderate  rain
R+ = Heavy rain
S- = Light snow
S  = Moderate  snow
S+ = Heavy snow
P  = Mixed or other precipitation
```

PRECIPITATION ACCUMMULATION MESSAGE FORMAT

Sent in response to command "A?"

```
x.xxxx
  or   ,xxxxx,xxxxx<end chars>
xx.xxx       |     |
  |          |     Total time of accumulation in minutes
  |          |
  |          |
  |      Instrument measurement time of accumuation
  |      in minutes (different from total time of
  |      accumulation if instrument is in intermittent mode)
  |
Accumulated precipitation in inches
```

CALIBRATION PARAMETER MESSAGE FORMAT

Sent in response to command "C?"

xxxx,sxx,xxxxx<end chars>

Temperature sensor calibration constant
(10000 nominal, typically 9000 to 11000)

EXCO calibration offset constant
(typically in range of -30 to +30)

EXCO calibration gain constant
(1800 nominal, typically 1500 to 2100)

OPERATIONAL DATA MESSAGE (Extended Format)

Sent when Operating State Word Bit 6 is "0".
Sent in response to command "D?".

PWxx,xxxx,xxxx,xxx.xx MI,cccccc,ccccc,x.xxxxx,xxxx.x F,xxxx,xxx.xx,xxx.xx,xx.xx,xxx,xxx,xxx,[illegible]

Remote Maintenance

Precipitation Indicator 2

Precipitation Indicator 1

Precipitation Message Index

Detector Background Illumination

EXCO less precipitation particle component (/KM)

Total EXCO (/KM)

Number of precipitation particles detected in last measurement period

Temperature (degrees F)

Amount of water in precipitation last measurement period (inches)

Obstruction to vision message

Precipitation type message

Daytime visual range (miles)

Time since this report was generated (seconds)

Last measurement period (seconds)

Instrument identification number

Remote Maintenance Values

ccc

O = IRED radiant power OK
X = IRED radiant power high or low
O = A/D measurements OK
X = A/D measurements high or low
O = Temp sensor OK
X = Temp sensor failed

OPERATIONAL DATA MESSAGE (Compressed Format)

Sent when Operating State Word Bit 6 is "1".
Sent in response to command "D?".

```
PWxxaaaaxxx.xxppoox.xxxxxtttt.txxx.xxccc<end chars>
 |    |     |     | |    |    |         |
 |    |     |     | |    |    |         Remote Maintenance
 |    |     |     | |    |    |
 |    |     |     | |    |    Total EXCO (/KM)
 |    |     |     | |    |
 |    |     |     | |    Temperature (degrees F)
 |    |     |     | |
 |    |     |     | Amount of water in precipitation in
 |    |     |     | last measurement period (inches)
 |    |     |     |
 |    |     |     Obstruction to vision code
 |    |     |
 |    |     Precipitation type code
 |    |
 |    Daytime visual range (miles)
 |
 |  Time since this report was generated (seconds)
 |
Instrument identification number
```

Precipitation Type Codes

00	No precipation
10	Light Drizzle
11	Moderate Drizzle
12	Heavy Drizzle
13	Mixed, Light Drizzle and Light Rain
14	Mixed, Moderate Drizzle and Light Rain
15	Mixed, Heavy Drizzle and Light Rain
20	Light Rain
21	Moderate Rain
22	Heavy Rain
30	Light Snow
31	Moderate Snow
32	Heavy Snow
40	Indeterminate Precipitation Type
43	Light Indeterminate Precipitation Type
50	Initial Value

Obstruction To Vision Codes

00	No Obstruction
01	Haze
02	Fog

Remote Maintenance Values

```
ccc
|||
O||  = IRED radiant power OK
X||  = IRED radiant power high or low
 O|  = A/D measurements OK
 X|  = A/D measurements high or low
  O  = Temp sensor OK
  X  = Temp sensor OK
```

MATRIX RESPONSE FORMAT

Sixteen lines are sent in response to the command "M?". Each line has at least one numeric value, but all zero value elements to the right of the last nonzero value element are removed. The maximum number of elements in a row is twenty-one (21).

```
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
Mnnn[,nnn...]<end chars>
```

PARAMETER MESSAGE FORMAT

Sent in response to command "P?"

```
TPWxx,cccccccc,bbbbbbbb,bbbbbbbb,xx,xxx,xxxxx,xxxx,xxx,xxx,xxxx,xxxx,xxx,xx,xxxxx<end chars>
```

- Instrument identification number
- Program revision (text)
- Processor board switch setting (binary)
- Operational state setting (binary)
- Offset value for EXCO (/KM)
- Maximum particle count in 5 measurement periods (for intermittent mode, the present period) to never be considered percipitation
- Minimum particle count in 5 measurement periods (for intermittent mode, the present period) to always be considered precipitation
- Adjustment factor, Precipitation particle size for its peak signal relative to the fog EXCO average signal
- 160 Hz filter particle size radius threshold (microns)
- 80 Hz filter particle size radius threshold (microns)
- Precipitation amount adjust
- Reserved
- Sample volume height adjust
- Particle minimum velocity to be precipitation
- Minimum particle count to use matrix more recent than 5 minutes for analysis

COMMUNICATIONS PARAMETERS FORMAT

Sent in response to command "PCn?".

```
xxxx,xccx
|     || |
|     || Stop Bits(1 or 2)
|     ||
|     |Parity Code
|     |  EE   Tx Even   Rcv Even
|     |  OO   Tx Odd    Rcv Odd
|     |  EO   Tx Even   Rcv Odd
|     |  OE   Tx Odd    Rcv Even
|     |  EI   Tx Even   Rcv Ignore
|     |  OI   Tx Odd    Rcv Ignore
|     |  NN   Tx None   Rcv None
|     |
|     Bits per Word(7 or 8)
|
 Baud Rate
   300
   600
  1200
  2400
  4800
  9600
```

NOTE:
Tx is for PW-402A-121 transmitted signal parameter value
Rcv is for PW-402A-121 received signal parameter value

REMOTE MAINTENANCE MONITOR MESSAGE FORMAT

Sent in response to command "R?"

xx.xx,xx.xx,xx.x,xx.xx,x.xx,0000,11,11,000,ccc<end chars>

O = AC Signal Start of A/D Conversion Active
X = AC Signal Start of A/D Conversion Failed

O = Sensor Head Sync Signal Active
X = Sensor Head Sync Signal Failed

O = A/D Busy Signal OK
X = A/D Busy Signal Failed

Reserved

Reserved

Reserved

Reserved

Data Acquisition Circuit Test Voltage
(05.00 is nominal)

Receiver background brightness voltage
(03.00 is bright day background)

Reserved

Reserved

Source optical power monitor voltage (05.00 is nominal)

TIMING PARAMETERS MESSAGE FORMAT

Sent in response to command "T?"

```
xxxx,xxxx,xxxx,xxx,xxxxx
```

Delay before each communications response line (0 to 10000 milliseconds)

Not used

Intermittent mode period (300 to 9999 seconds)

Time between measurements of peripheral signals during measurement interval (5 to 9999 seconds)

Measurement interval for each operational data message (30 to 9999 seconds)

END
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